THE STORY OF BIOLOGY

Formerly The Growth of Biology

By

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"BIOLOGY AND ITS MAKERS"

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To

E. E. L.

PREFACE

THIS volume is an attempt to picture under one view the steps in the growth of our knowledge of organic nature from the Greek foundation to Cuvier in zoölogy, Hofmeister in botany and Claude Bernard in physiology. It is not strictly limited to the periods indicated; in some instances the story has been carried to a later date as in the cases of protozoa, insects, and the classification of animals.

The growth of our knowledge of living organisms is a part of the larger story of human progress; the struggles and triumphs of the human spirit. In a history of any science it is not sufficient to give an impersonal account of the discoveries as coming in a certain sequence — the human element is involved as an essential part of the story. Progress is the result of human endeavor, and in the history of biology one part of the task is to depict the striving of individuals to comprehend the phenomena of nature as manifested in living beings, leading up to man himself. "It is the flow of mind towards creative production that makes civilization and that has made man what he is." With this in mind, in the following pages sidelights on the personal character and training of the pathfinders of biology will be included along with their discoveries.

The changes that have come about on account of the progress of biological science have resulted in freeing the mind from certain hindrances to advance and have supplied discoveries of inestimable value to our race. There has been continuity of development only in a general way, often interrupted by social conditions and with many a backset. Development is conditioned on the state of civilization and the condition of knowledge at a certain era; "No man can advance much beyond the knowledge of his time."

The book has been written from an examination of the original sources, for access to which I am especially indebted to the Surgeon General's Library, Washington, the John Crerar Library, Chicago, and the Pierpont Morgan Library, New York City. At the same time I have made copious use of the writings of others on the topics discussed. The pictures have been photographed by the author from the original printed editions of early naturalists, from old prints and from other book illustrations. A selected reading list of the more easily accessible books and articles has been included at the end of the volume.

I am deeply indebted for suggestions and various kinds of assistance to my colleagues, Charles B. Atwell and Henry Crew, as well as to Walter Libby of Pittsburgh and Lynn Thorndike of Cleveland, all of whom have read the manuscript. I owe a debt of especial obligation to Mr. Lincoln MacVeagh, who in an early stage of the work supplied invaluable criticism and suggestions as to form and proportions of the work; and, finally, to my wife, Ellen Eastman Locy, without whose encouragement and continued interest the book could scarcely have been completed.

W. A. L.

PUBLISHERS' NOTE

THE author had completed *The Story of Biology*, but it had not been sent to press when his untimely death occurred, October 9, 1924. Professor J. H. Gerould of Dartmouth College kindly consented to read the galley proofs, and Mr. A. W. Burnett the page proofs.

While the present volume is complete in itself it should be said that the author had hoped to treat the history of the doctrine of organic evolution, of genetics, and certain kindred topics in a second volume. His sudden death made it impossible for him even to start this supplementary volume.

August, 1925.

CONTENTS

CHAPTER		PAGE
I.	Some General Considerations Regarding Biological History	3
II.	The Natural History of Antiquity	13
III.	Greek Science in Alexandria	39
IV.	Natural History During the Roman Period	47
V.	From Galen to the Thirteenth Century	72
VI.	Some Natural History Writings of the Thirteenth Century — Albertus Magnus and Others	89
VII.	The Earliest Printed Illustrations of Natural History	103
VIII.	The Herbals of the Sixteenth Century	126
IX.	Vesalius and the Overthrow of Authority in Science	153
X.	William Harvey and Experimental Observation	179
XI.	Primitive Microscopes and the Discovery of Micro-Organisms	196
XII.	Three Naturalists of the Seventeenth Century — Malpighi, Swammerdam and Leeuwenhoek	225
XIII.	Monographs on Insects and Other Minute Animals	256
XIV.	Gesner and Other Pioneer Naturalists	283
XV.	Reform of the Linnæan Classification of Animals	322
XVI.	Cuvier and the Comparative Anatomy of Animals	334
XVII.	Progress of Botany from Linnæus to Schleiden	360
XVIII.	Plant Anatomy, Histology and Physiology from Linnæus to Sachs	382
XIX.	The Period of Hofmeister	416
XX.	Physiology from Harvey to Claude Bernard	437
	Index	471

ILLUSTRATIONS

FIGURE		PAGE
1.	Prehistoric Sketch of Red Deer	15
2.	Restoration by Sir E. Ray Lankester	16
3.	The Browsing Reindeer, with a Paleolithic Landscape	17
4.	Aristotle, 384–322 B.C.	22
5.	Aristotle: From Herculaneum; Probably Fourth Century	23
6.	Theophrastus, 372–288 B.C.	35
7.	Pliny, the Elder, 23–79 A.D.	49
8.	Dioscorides, 130–201 A.D.	56
9.	Seedling Bean	60
10.	Galen, 131–200 A.D.	64
11.	Avicenna, 980–1037	84
12.	Averroës, ca. 1126–1198	86
13.	Albertus Magnus, ca. 1193–1280	93
14.	Tracing of Four Figures from a Folio Plate of Twelve Quadrupeds	112
15.	Tracing of the Falcon	113
16.	Photograph of a Folio Plate of Invertebrates	114
17.	Photograph of One of the Two Botanical Plates	115
18.	Photograph of a Folio Plate of Animal Figures	116
19.	Animal Pictures from the Diologus Creaturarum	117
20.	Photograph of a Folio Plate of Animals	118
21.	The Yellow Flag	122
22.	The White Lily	123
23.	The Fox	124
24.	Otto Brunfels, 1464–1534	128
25.	Plantago	129
26.	Lily of the Valley	130
27.	Leonhard Fuchs, 1501–1566	133
28.	Hieronymus Bock, 1498–1554	137
29.	Valerius Cordus, 1515–1544	140
30.	Conrad Gesner, 1516–1565	145
31.	Pierandrea Mattioli, 1501–1577	147
32.	Caspar Bauhin, 1560–1624	149
33.	Andrea Cesalpino, 1519–1603	150
34.	The Single Picture in the Melerstat Edition of Mundinus, Leipzig, 1493	158
35.	Anatomical Sketch from I Manoscritti di Leonardo da Vinci, 1510	162
36.	Jacobus Sylvius, 1478–1555, Teacher of Vesalius	164

FIGURE		PAGE
37.	Andreas Vesalius, 1514–1564	169
38.	Anatomical Sketch from Vesalius' *Fabrica*	170
39.	The Skeleton from the Same Book	171
40.	Initial Letters from the *Fabrica* of 1543	172
41.	Gabrielle Fallopio, 1523–1562	176
42.	Eustachi in His Anatomical Theater at Rome	177
43.	Bartolomeo Eustachi, 1524–1574	178
44.	Anatomical Theater at Padua in Harvey's Time	184
45.	William Harvey, 1578–1657	186
46.	Sketch of the Portal Circulation According to Vesalius	191
47.	Earliest Known Printed Picture of the Simple Microscope, 1637	200
48.	Descartes' Representation of an "Ideal Microscope," 1637	200
49.	Kircher's Microscope, 1646	202
50.	An Early "Flea-Glass" with Ornamentation of the Tube	203
51.	Early Microscopes from Schott's *Magia optica,* 1671	204
52.	Hooke's Compound Microscope, about 1660	205
53.	A Leeuwenhoek Microscope in the University of Utrecht	210
54.	To Show How the Leeuwenhoek Microscope Was Held	211
55.	A Leeuwenhoek Microscope Provided with a Concave Reflector	211
56.	Leeuwenhoek's Arrangement for Viewing the Circulation of the Blood	212
56A.	Photograph of the Original Plate of Bacteria as seen by Leeuwenhoek, 1683	215
57.	The Capillary Circulation as Pictured by Leeuwenhoek, 1686	218
58.	First Printed Picture of the Amœba, 1775	219
59.	Otto Fr. Müller, 1730–1784	220
60.	Micro-organisms from Müller's *Animalculæ infusoria,* 1786	221
61.	Ehrenberg, 1795–1876	223
62.	Marcello Malpighi, 1628–1694	230
63.	Sketches of the Anatomy of the Silkworm	237
64.	Jan Swammerdam, 1637–1680	241
65.	From Swammerdam's *Biblia naturæ,* 1737	247
66.	Anatomy of Insect Larva	249
67.	Antonj van Leeuwenhoek, 1632–1723	251
68.	Pierre Lyonet, 1707–1789	258
69.	Larva of the Willow Moth	259
70.	Muscles, and Central Nervous System with the Nerves of the Willow Moth	260
71.	Dissection of the Head of the Same Animal	261
72.	Brain and Nerves of the Head	262
73.	Lyonet's Dissecting Outfit	263
74.	René-A.-F. de Réaumur, 1683–1757	264
75.	Charles Bonnet, 1720–1793	265

FIGURE		PAGE
76.	Rœsel von Rosenhof, 1705–1759	267
77.	Charles de Geer, 1720–1778	268
78.	Nervous System of the Cockchafer	271
79.	Franz Leydig, 1821–1908	273
80.	J. Henri Fabre, 1823–1913	276
81.	Trembley's Original Sketches of Hydra, 1744	279
82.	Illustrating some of Trembley's Experiments with Hydra	280
83.	Pierre Belon, 1518–1564	286
84.	Human Skeleton	287
85.	Bird Skeleton to Compare with Fig. 84	288
86.	Guillaume Rondelet, 1507–1566	289
87.	Conrad Gesner, 1516–1565	289
88.	Rabbits from the First Edition of Gesner's *Historia animalium*, Zurich, 1551	292
89.	Woodcut of the Mule	293
90.	Deer	294
91.	Basket Star	295
92.	Sketch of the "Su"	296
93.	Ulisse Aldrovandi, 1522–1605	299
94.	John Ray, 1628–1705	306
95.	Francis Willughby, 1635–1672	307
96.	Linnæus at Sixty	316
97.	Lamarck's Sketch of the Genealogical Tree of Animals	324
98.	Karl Th. von Siebold, 1804–1885	327
99.	Rudolph Leuckart, 1823–1898	329
100.	Pieter Camper, 1722–1789	336
101.	John Hunter, 1728–1793	337
102.	Félix Vicq-d'Azyr, 1748–1794	341
103.	Georges Cuvier, 1769–1832	346
104.	Cuvier at the Zenith of his Power	347
105.	Henri Milne-Edwards, 1800–1885	350
106.	Henri de Lacaze-Duthiers, 1821–1901	351
107.	Richard Owen, 1804–1892	355
108.	J. Fr. Meckel, 1781–1833	356
109.	Karl Gegenbaur, 1826–1903	357
110.	E. D. Cope, 1840–1897	358
111.	Joseph Pitton de Tournefort, 1756–1808	362
112.	Linnæus in his Lapland Dress	365
113.	Bernard de Jussieu, 1699–1777	369
114.	Antoine L. de Jussieu, 1748–1836	370
115.	Augustin Pyramus de Candolle, 1778–1841	372
116.	Robert Brown, 1733–1858	376
117.	Microscopic Structure of Oak Wood	383
118.	Cells in a Spine of the Gourd	384
119.	Nehemiah Grew, 1641–1712	385
120.	Microscopic Structure of a Vine Plant	386

FIGURE		PAGE
121.	Microscopic Structure of a Sumac Stem	387
122.	Hugo von Mohl, 1805–1872	390
123.	Carl von Nägeli, 1817–1891	393
124.	Stephen Hales, 1677–1761	398
125.	Jan Ingen-Housz, 1730–1799	401
126.	Théodore de Saussure, 1767–1845	405
127.	Julius von Sachs, 1832–1897	408
128.	Rudolph Jacob Camerarius, 1665–1721	410
129.	Joseph Gottlieb Koelreuter, 1733–1806	411
130.	Matthias Jacob Schleiden, 1804–1881	418
131.	Wilhelm Hofmeister, 1824–1877	429
132.	Albrecht von Haller, 1708–1777	441
133.	Lazzaro Spallanzani, 1729–1799	445
134.	Sir Charles Bell, 1774–1842	448
135.	François Magendie, 1783–1855	450
136.	Johannes Müller, 1801–1858	453
137.	Carl Ludwig, 1816–1895	457
138.	Emil du Bois-Reymond, 1818–1896	459
139.	Herman von Helmholtz, 1821–1894	461
140.	Claude Bernard, 1813–1878	466

THE STORY OF BIOLOGY

CHAPTER I

SOME GENERAL CONSIDERATIONS REGARDING BIOLOGICAL HISTORY

Recent years have witnessed a marked increase of public attention to biological matters. Perhaps the first strong impulse in this direction dates from 1859 when the doctrine of organic evolution was revived in a new form. The discussions that raged about that doctrine created a great stir and made the reading public conscious of biology as a subject of broad human interest. Up to that time it had claimed the attention of a number of investigators, but had received little notice from the general reader who was too ready to regard it as a technical field of learning. After 1860, however, the masses who never before had given consideration to a subject of this nature, became interested in some phases at least of biological investigation. Once awakened, this interest was kept alive by a succession of brilliant discoveries. The investigations of Pasteur, Lister, and Koch, which followed closely upon the pronouncement of Darwin, opened the way to experimental and preventive medicine in which the public could not fail to take an interest. Largely as a result of their investigations came the rise of bacteriology. The germ theory of disease was demonstrated, the nature of infections was elucidated and in the train of the studies referred to came new knowledge of immunity, of the production of toxins and antitoxins within the living body, and the theory and practice of serum inoculations and vaccinations. The practical applications of biological discoveries to the benefit of mankind enhanced in the public mind the value of biological investigations and served to increase the general interest in biological advances.

A widening horizon inevitably came to those who ventured into the territory of biology and new points of interest emerged.

For illustration, the subject of heredity was being actively investigated by biologists, and, since the wish to understand the nature of inheritance of physical and mental qualities is well-nigh universal, the public has taken a keen interest in the results of the experimental study of heredity. The credit for introducing experimental methods into the subject and of fixing attention on the inheritance of particular characters belongs chiefly to Mendel and to Galton. As is well known, however, Mendel's very notable investigations, although published in 1866–1867, were overlooked, and it was not until the rediscovery of his principles at the opening of the twentieth century that the experimental study of inheritance became a much pursued subject even by biologists. Beginning in 1901, numerous experimental studies on a wide scale of inheritance, in both animals and plants, have made the so-called Mendelian inheritance one of the most actively pursued subjects of biological investigation.

As public interest widened and increased, a desire sprang up for further knowledge of biology and its earlier history began to be looked into. For example, the circumstances connected with the description of protoplasm (1835) and with the formulation of the cell-theory now became known and appreciated; the great progress of embryology and physiology in the nineteenth century, though a little more remote from the field of general interest, also came under consideration along with other notable developments which shared in the creation of biology.

Thus, today, the place of biology in public esteem and public consideration is well established, and the time is ripe for a comprehensive and untechnical account of its history. For no sooner does one become interested in an achievement than he wishes to know its antecedents, and begins to inquire into the various stages of its history. We understand best those things which we know in their origins. The story of how human interest in plants and animals started and developed is essential to comprehending the service of biology to human progress. No one can follow the history of the rise of biological ideas without being

convinced that the interpretations of nature from biological analysis have "freed the human spirit from some traditional hindrances to development and have played an important part in intellectual progress." The various applications of biological discoveries to the welfare of mankind supply one of the most striking examples of benefits accruing from investigations in pure science.

Dr. George Sarton has pointed out the most neglected factor in the writing of history. "Human progress is largely a product of the development of science, and a general history of which the fundamental theme is not the history of science cannot be complete." There are many indications that this neglect of science as a dominant influence in the progress of civilization is on the way to be remedied. In the last twenty-five years a wave of interest in the history of science has spread over Germany, England, France, Italy, and the United States. It is perhaps better developed in the direction of the history of medicine and its related branches than in any other field. Different societies, institutes, and periodicals devoted to the history of science have arisen; professorships in the history of medicine and the natural sciences have been created; courses in the general history of science and in the individual sciences have been introduced into the universities. As examples of this movement, I mention only the magisterial work of Karl Sudhoff and his collaborators in Germany; the fine work of the Oxford School for the history of science, nurtured by Sir Michael Foster and Sir William Osler, and now carried forward by Charles Singer and his associates; and the active movement for the history of science in Italy. The development of this subject in the United States is shown in the publication of histories of science by native authors, (Libby, Sedgwick and Tyler, Garrison, Thorndike); and in the launching of several Annals, Bulletins, etc., for the history of medicine. The editorship of *Isis*, a periodical devoted to the publication of historical researches in all sciences, has also been located here. Outside strictly scientific circles there has been established a section for the history of science by

the American Historical Association (1920). This was followed by the organization of a section for the history of science by the American Association for the Advancement of Science in 1921.

All these signs in Europe and on this side of the Atlantic give promise that science as an agency in the history of civilization is to become generally recognized as an essential factor of progress, and soon will be ranked by writers of history along with the artistic, the literary, the religious impulses, the struggle for political freedom, and the development of legal guarantees of human rights — all of which have been so long recognized as deserving of historical treatment.

To treat the history of science as a whole would present especial difficulties. It would be like writing a history of mankind, tracing concurrently the progress of all races and all governments. In a general history of science there are so many aspects to be considered that the account is likely to become prolix if not superficial. In such a complicated narrative it would scarcely be possible to give in reasonable compass the details necessary to show the inter-relations between different movements. For the sake of clearness, other forms of historical writing supply individual treatises on different nations, on particular periods of time, and on particular movements. So in the history of science we obtain greater clarity and succinctness if we take up separately the story of the progress of individual sciences.

But it may truthfully be said that an appreciation of achievement and progress in any particular science requires some first-hand knowledge of the science dealt with, and that the various sciences have become so specialized and so extensive that no single individual can have first-hand knowledge of them all. Instead of a history of biology, therefore, a separate treatment of botany — as in Meyer's history of botany; and of zoölogy — as in Carus's history of zoölogy; or in treatises covering a limited period (Sachs's history of botany and Michael Foster's history of physiology), would at first appear to be more logical. But the two lines of investigation involved in botany and zoölogy are

so generically alike that, however difficult it may be to preserve a proper balance, there are advantages in bringing all biological progress under one point of view. Just as Sir Douglas Haig clarified his problem by treating of the great war — with all its details — as one continuous engagement, so the progress of biology may be pictured as one continuous effort on the part of individuals to analyze and reduce to system the knowledge of living organisms, and, finally, to interpret the phenomena of their life.

Moreover, botany and zoölogy have developed along parallel lines; the great generalizations of biological science have been derived from the study of both plants and animals. In the later mediæval period, indeed, botany was in the lead because a knowledge of the medicinal properties of herbs was of practical importance to the medical men. For some time thereafter botany and zoölogy developed quite separately, but in their period of great growth during the nineteenth century these sister sciences contributed equally to the study of microscopic structure, the investigation of protoplasm, the formulation of the cell-theory, the development of cytology, experimental investigation of heredity, and the study of organic evolution. It is not insuperably difficult to treat them together up to the middle of the nineteenth century, but beyond that point no one except a professional botanist or zoölogist can give an adequate interpretation of the progress of his particular science.

Biological progress should rather be represented as a stream of thought than as a mere accumulation of facts about animals and plants. A chronological record of the discovery of individual facts would be tedious and in itself of little worth, but the story of the struggle of mankind to attain a knowledge of living nature based on observation, experience, and reason is of inspiring interest. It is part, indeed, of the great struggle of the human spirit for self-expression.

In surveying the route along which biology has traveled we should determine the conditions under which the science arose, the atmosphere which it created, how it reacted towards the

thought of the time, and how the thought of the time reacted towards it. We should also make the acquaintance of its foremost exemplars, those men who through natural gifts and unexampled industry accomplished results of lasting importance. The discoverers of individual facts are many, the organizers of scientific ideas few, but of greater importance. Our chief concern should therefore be with the great pathfinders, and our purpose should be to determine the epochs of biological progress — to emphasize the main scenes and the chief actors.

Before attempting to do this, however, we should briefly consider the sources of natural history and the circumstances under which it obtained its rise. We cannot expect to find any degree of scientific insight in the earliest observations of nature. The animated world impressed itself naïvely on the senses of primitive man. His first accumulated knowledge of animals and plants was merely a congeries of sense-impressions conveying hints of danger or usefulness, and his development of scientific insight was necessarily a long and slow process. Scientific insight aims at the representation of things of nature as they are. But things are not first seen as they are; they appear as our minds make them. The mind of primitive man opened slowly to vague wonderings of the relations of cause and effect — gropings towards the meaning of natural phenomena — a higher step than mere sense-impressions. The awe-inspiring flash of lightning, the roar of the thunder, the flood, the movement of plants and trees produced by the wind, the darkening of the face of the moon, the stealthy approach of ferocious beasts, the stinging and poisoning of plants, death, violent and natural, the ravages of disease, all to him mysterious — these tended to arouse feelings of awe and a belief in the existence of malign forces outside himself. Thus arose in the mind of primitive men the most fantastic misunderstandings regarding nature and its various manifestations. They peopled the world with malign influences, with spirits and demons to be outwitted or propitiated. Superstitions arose and were passed along by tradition. The ritual of magic developed along with these superstitious beliefs, and thus primitive nature-

searchers became devotees of magic as well as priests and medicine men.

After primitive man was well started on his ascent, his observations of animals and plants were still crude and almost meaningless. They can scarcely be called biological. It is convenient to designate them under the title of natural history and to designate the men engaged in them as primitive naturalists, or primitive nature-searchers. The starting point of natural history is lost in the past. Long before written history began there were nature-lovers and nature-searchers. Aristotle (325 B.C.) in his writings about animals refers to the "ancients" and mentions previous writers whose contributions he had examined in preparing his zoölogical treatises. Likewise, Theophrastus, "the father of botany," makes mention of numerous observers of plants before he systematized the subject.

We no longer regard it as strange that Aristotle should speak of the "ancients" since we have recovered inscribed codes of law and medical manuscripts, as well as other literary monuments, which date from many centuries before Aristotle. Hammurabi, king of Babylonia, set up (about 2100 B.C.) in the capital of his kingdom a monolith upon which were engraved laws relating to nearly all human relations. The legal rights of the people to property and protection had for many centuries received attention before they were codified and made public property. Even at this early date, medical practice was regulated and penalties were prescribed for blunders and injuries in surgical practice. Among the medical treatises, that known as "Ebers Papyrus" (about 1550 B.C.) is the most complete and represents the winnowings of several centuries of medical practice. "But," says Garrison in his history of medicine, "even antedating these are certain pictures engraved on the door-posts of a tomb in the burial ground near Memphis and described by their discoverer (1906), W. Max Müller, as being the earliest known pictures of surgical operations (2500 B.C.)." Thus, at a date about as far back of Aristotle as Aristotle is back of our time there were pictorial representations — and doubtless writ-

ings that have been lost — relating to medical practice. Since primitive people rise slowly from aboriginal conditions, the inference may be drawn from these human documents that they had been preceded by many centuries of observation as well as crude attempts to make use of these observations. This brings us naturally to speak of the great antiquity of human culture.

GREAT ANTIQUITY OF HUMAN CULTURE

With all his psychical peculiarities, aboriginal man must have been keenly observant and self-reliant, since he had to cope with the practical questions of food, clothing, and defense against animals stronger than himself and provided by nature with weapons of attack and defense. This pre-human was not stupid and merely bestial, but forceful and alert. In order to protect himself and his family and to establish his supremacy over nature, he was compelled to match his wits against most adverse conditions. Forced to dispute the territory with fierce animals he needed intelligence and device, and it was by the possession of these qualities that he won his place at the head of all nature. The early hunters learned something about animals and laid the foundations of a primitive zoölogy; also, because of its practical importance, a knowledge of the medical properties of plants was gradually acquired. We know little about the conditions of aboriginal life and of the upward struggle of the human spirit except that, even before we get the first recorded trace of it, the time consumed was very long.

What little is known of the life of primitive man is based on collections of his stone implements, traces of his camp sites, and crude sketches of extinct animals made by prehistoric artists. That the feeling of craftsmanship and the creative impulse were developed long before written history began is shown by improvement in the manufacture of primitive flint implements and progress of pictorial representation. Even in the palæolithic period of prehistoric man (more than 100,000 years ago), not less than six distinct culture-periods have been traced — each extending over many centuries. The representations of prehis-

toric art are very extensive, leading from crude pictures of the Aurignacean culture-period in central Europe and southern France, of the mammoth, reindeer, and of other animals, scratched on bone, ivory, horn, slate, etc., up to such fine examples as the polychrome representations of the bison and other animals found on the walls of the cave of Altamira in Spain — made by men of the Magdalenian period, as recently as 25,000 years ago.

Just as some minds had a feeling for artistic expression and became primitive artists, so others by temperament and natural inclination observed nature, dreamed, and speculated on the meaning of the things they saw and became the primitive nature-lovers. The combined character of priest, medical man, magician, and naturalist, which belonged at first, by force of circumstances, to every gifted man, gradually grew more specialized, as families gathered into groups and life became relatively less precarious. Mental and spiritual differences began to separate people into different classes; a man had some chance to follow his bent. Priests now instructed and led the people; medical men ministered to their infirmities; and these had need of knowledge of nature and cultivated it. On the other hand, those so inclined by natural gifts were free to gather lore about animals and plants and *began to enjoy it.* The beginning of enjoyment in such pursuits was the outcropping of intellectual pleasure and marked a new and potent force for improvement.

This new impulse to human progress promoted all kinds of self-expression, artistic, literary, and scientific. Those who enjoyed intellectual speculation developed into the theologians and metaphysicians of the early world; those who held closer to the objective search of nature became the primitive naturalists and savants. Thus arrived the dawn of intellectual pursuits, the inquisitive mood made its conquests and the speculative mood prospered. After centuries this resulted in breeding a race of men who found enjoyment in discovery and in the pursuit of truth.

Along with these aspirations came many subtle changes of

spirit. There came a certain exaltation of feeling in the discovery of beauty and harmony in the world, the vague comprehension of the adjustments of nature and the gradual conception of a Divinity that controls and directs the affairs of the world. At first awe-stricken and apprehensive, possessing a belief in magical influences of a malign nature, man developed a religion founded on fear, and only at length evolved a religion founded on love and devotion. In the meantime the nature-searchers were getting increased satisfaction from discovery. To quote Malpighi, a much later pioneer, but one who worked upon his observations with quite primitive enthusiasm and devotion, "In performing these researches so many marvels of nature were spread before my eyes that I experienced an internal pleasure that my pen could not describe." Although unrecorded, we may assume from human nature that early searchers had similar feelings. Investigations of the most widely separated primitive peoples have demonstrated the essential unity of folk-tradition and the possession of similar mental and spiritual attributes. There is some reason for believing that, although science was first developed to meet practical needs, the pursuit of knowledge eventually gave rise to a psychological compensation among primitive people, which played no small part in their intellectual development.

But our glimpses of prehistoric man are shadowy, and it is not necessary to go deeply into archæological researches to understand the rise of natural history. The natural history of the ancients can be treated with the utmost brevity. In a later chapter, we shall come down to a time in the ancient world when achievements were considerable, when science as a whole had been organized, when innate inquisitiveness had accumulated a large store of information about natural phenomena and had organized this knowledge into a fairly compact system.

CHAPTER II

THE NATURAL HISTORY OF ANTIQUITY

In the previous chapter the great antiquity of human culture was referred to, and, if we would catch a glimpse of rudimentary science, this feature cannot be entirely disregarded. Natural history did not begin with the first books that were written about animals and plants, nor were the men who wrote these books the first naturalists. We have convincing evidence that, many centuries before the writings of Homer, Hippocrates, and Aristotle, observations of animals and plants were made by a primitive people who lived in southwestern France and Spain. These observations were recorded in pictures which reached a high grade of accuracy, especially for the animals as regards form, posture, and movement. To begin the story of natural history from written records, which came a long time after, is to build on a more secure foundation, but we should at least take a glimpse at these earlier productions of the human spirit.

With the progress of archæological investigation it becomes more and more clear that there was not merely a single race of primitive people standing in direct line as the progenitor of the modern races. There were several prehistoric races having a parallel development and, just as in the history of lower animals some forms became extinct and are known only as fossils, so some of these races of men disappeared after an existence of many thousand years and are only known to us through their fossil remains and stone implements. Several prehistoric races succeeded one another. It is also becoming clear that there lived during the last part of the palæolithic era a highly gifted race which has left records in the form of pictorial representations of animals and plants. These were the Crô-Magnons, deriving their name from the little hamlet of Crô-Magnon in southwestern

France, in a grotto near which their skeletons were first found about 1835. The stone implements of this race are distinctive, and there are some evidences of their migration from Africa to Spain and from Spain into France — all this, however, is at present very obscure and uncertain. Apparently, the Crô-Magnons entered France about 50,000 years ago and overthrew the Neanderthalers, dispossessing them of their shelters. As implements of culture and industry show, they occupied the same caves, grottoes, and camp sites as the Neanderthalers — industrial remains of the two races existing in combination, except that the Crô-Magnon implements are in more recent deposits and associated with the bones of more recent animals. The skeletons and skulls show that the Crô-Magnons were a fine, tall race with a large brain; modern as to structure of their bony frame-work, including teeth and a chin — the latter lacking in Neanderthalers. The average cranial capacity of the Crô-Magnon skull is greater than the average cranial capacity of present-day white Europeans. So far as known at present, the Neanderthalers became extinct, and for 25,000 years the Crô-Magnons occupied the stage in central and southwestern France and in northern Spain.

EARLIEST KNOWN PICTURES OF ANIMALS

One point of great interest is that some of the Crô-Magnons were temperamentally inclined to express themselves by pictures, and began to make records of their observations on animals, engraved on ivory, horn, bone, flat rocks, and later, on the walls and ceilings of caves. These sketches, at first crude, with the progress of time became accurate; they exhibit the evolution of prehistoric art and, at the same time, make us acquainted with the growth of powers of exact observation.

An immense number of these pictures are known representing the mammoth, the horse, the reindeer, the red deer, the cave bear, the cave-lion, hyena, bison, aurochs, grouse, ptarmigan, etc. They are by no means sporadic, but are distributed over a wide geographical area, indicating that there were many indi-

viduals who observed and sketched with varying degrees of skill. Bearing in mind that the purpose of the pictures as well as the life and social condition of this remote people is conjectural, the great number of pictures suggests that there might have been a guild of picture-makers whose occupation was passed on from generation to generation. The better class of pictures cannot be interpreted as the sudden inspiration of untutored savages; some of the best bear internal evidence of careful and prolonged observation. The artists were wonderful observers of limb motion (Fig. 1), and many drawings show exact proportions of head,

Fig. 1. — Prehistoric Sketch of Red Deer: The Original as Rolled Off from the Cylindrical Surface on Which It Was Engraved. (Cave of Lortet, 1873.)

body, limbs, horns, hoofs, etc.; others show posture, locomotion, fighting, herding, and migration.

For illustration of the spirit and the quality of these animal pictures we shall choose two of closely related animals — to show that in drawing animals the artists did not generalize, and confuse closely related forms, but were accurate in detail. The picture of the red deer shown in Fig. 1 was found at Lortet, France, in 1873. It is engraved on the curved surface of an antler of the same species. It is an example of a die engraved on a cylinder-like surface which can be rolled off into a flat picture. It is spoken of by Sir E. Ray Lankester and the artist-naturalist, Walter Winans, as superior to the pictures of animals by modern

artists, because truer to nature and showing more accurate observation of proportion of parts and posture. Speaking of the three red deer, shown in Fig. 2, Winans says: "I agree that the picture is wonderful — better than anything Landseer or Rosa Bonheur drew, because these latter were only artists; one can see by their pictures (full of faults as to attitudes and actions) that they knew nothing about deer. For instance, Landseer's

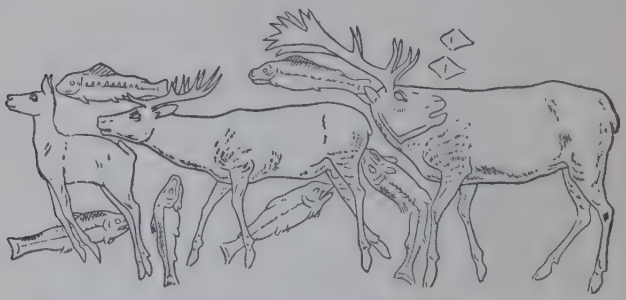

FIG. 2. — RESTORATION BY SIR E. RAY LANKESTER. (*Secrets of Earth and Sea.*)

stags are much too big in the body and their heads are too small, and even the shape of their horns is conventional. . . . The Lortet drawings enable one to know all details about the three red deer." This picture is a composition showing the retreat of a family of red deer from threatened danger and in the act of crossing a stream in which there are fishes. The big stag guarding his family from the rear is scenting the air, the calf in front is sportively springing.

The browsing reindeer (Fig. 3) affords a good contrast with the foregoing because the two are closely related animals, and still are not confused as to proportions of body, horns, limbs, etc. This engraving on a piece of reindeer antler is "a unique instance of the portrayal of landscape in palæolithic art." Both pictures are true to nature and imply an intimate acquaintance with the animals sketched as well as a considerable degree of mental discrimination. In fairness, we should accord to these

earlier people some knowledge of animals based on observation — and this, at least, is primitive natural history. We might even designate the designers as artist-naturalists rather than merely as primitive artists.

The Crô-Magnons were hunters and doubtless a large part of the life of the men was spent in observing animals. While the men observed animals and engaged in the chase, the women, who mothered and tended the families, became the nurses. They learned by experience the healing properties of plants, and perhaps served as medical consultants and compounders of medicines. Thus a knowledge of plants as well as that of animals was acquired.

The colored pictures on the walls of caverns, as at Altamira, Combarelles, Font-de-Gaume and other places, reached the crest of artistic expression in prehistoric times. It is a natural in-

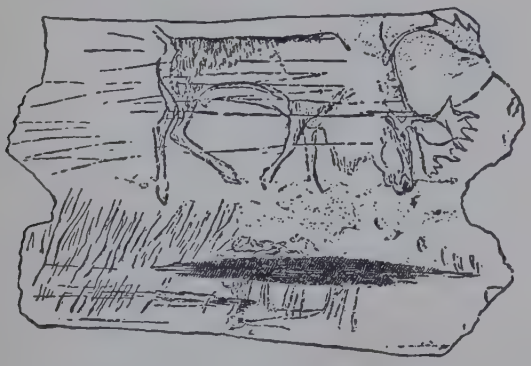

Fig. 3. — The Browsing Reindeer, with a Paleolithic Landscape. (Donald A. MacKenzie, *Ancient Man in Britain*, 1822.)

ference that the purpose of these sketches was primarily magical, rather than scientific — to secure some magical influence over the animals depicted, — but, as Frazer, Thorndike, and others have shown, early magic was closely related to early science as well as to early religion. At the same time, these sketches show trained observation, and they represent a part of the animal lore

of a period long before written history. These records of the Crô-Magnons are evidences of observations on animals, and although we have no knowledge that a heritage of observation was passed along, we find Aristotle illustrating his treatises on animals by drawings to which he specifically refers. Aristotle was not a beginner; he had his predecessors in graphic representations as well as in written accounts of animals.

The existence of these prehistoric records of observation supports the conclusion that science, like other human institutions, has passed through a long embryonic period. The earliest written records which are extant bring us into the period of its infancy. The first well-marked epoch of natural history of which we have a remaining literature was among the Greeks in the time of Aristotle. We must give attention to Greek science because it was the best science of antiquity, and, especially, is this true in reference to natural history. With the Greeks we are practically at the source of natural history as a science and, except as foreshadowings, we may disregard the natural-history attainments of the immediate pre-Hellenics. We shall also neglect the appearance of indigenous science in Babylon, Egypt, and India, and all eastern countries with which history deals, and limit our story to the progress of science in Greece and western Europe.

GREEK SCIENCE AND MODERN SCIENCE

Before entering upon an account of the natural history of Aristotle and Theophrastus it will be helpful to take a brief glance at the immediate antecedents and character of Greek science as a whole.[1] Greek science did not spring full-orbed into existence among the Greeks; we find its early traces among the Ionian colonies in the seventh century B.C., but its roots extend further back into earlier nations. The Ionian Greek inherited

[1] Charles Singer, in his introductory lecture to a course on the history of science, delivered at University College, London, in 1920, brings out with great clearness resemblances and differences between Greek science and modern science. I have borrowed freely from this lecture.

from Mesopotamia a mass of effective observation, embracing mathematical and astronomical conceptions. From Egypt he derived knowledge of mechanical devices, of the reckoning of time, of drugs and probably of geometry. But the knowledge of medicine which is closely related to natural history probably came by the way of Crete. The relatively recent exploration and excavation of early sites in Crete "have afforded the most extraordinary evidence of the existence of a highly advanced civilization going far behind the historic period." The earliest writings on Greek medicine, in the seventh century B.C., presuppose long generations of research and careful record of observations, and the sources are now believed to be Minoan.

Before the advent of the Greeks science was an anonymous social product; the Greek however thought and worked as an individual, so that, beginning with the Greek period, we have contributions to knowledge connected with the names of individuals. This people also developed an idea of the unity and constancy of nature; their conception that the formation of organized beings is a continuous and orderly progress vaguely foreshadows the doctrine of evolution. The conviction that order reigns in nature "is their greatest and most vital contribution to scientific thought." It is this "which marks off their view of the Universe from that of all other ancient and from all primitive people." In these two particulars Greek science and modern science are alike.

In two other features Greek science differs from modern science and these are detrimental to the former and exceedingly annoying to us. Greek science arose as an offspring of philosophy and is at all times clearly connected with philosophy so that its speculative character is prominent and makes it difficult to follow with satisfaction. Also, the method of the Greeks was especially faulty, because it recorded, as a rule, only conclusions and not processes, a fact which greatly retarded progress after the Renaissance. The results of the ancients, it was found, could not be tested and impersonally verified by repeating their investiga-

tions. Being in the dark regarding the processes by which most of their results were reached, modern investigators cannot go over the same ground and make judicial analysis.

This is a great defect but it is less marked in some individuals than in others. Theophrastus often refers to the observations upon which his conclusions are based, and when Aristotle describes the embryonic stages of Sepia and of the chick, we can see with the material before us that he based his descriptions on observation — but a large number of his conclusions are speculative and general rather than specific. Galen, whose work is a part of later Greek science, must also be defended against the too strict application of the general statement. In his *Natural Faculties* he is very specific in describing experiments on the function of the ureters.

In the records of modern science, on the other hand, we uniformly find accounts of the material used for research, the way in which it was treated, the reagents employed, the entire process of getting it ready for examination described in detail and applied specifically to the form under observation. Then follow descriptions and sometimes sketches, and finally the results based on the observations, the particular technique, and methods. The whole makes a production that can be verified or rejected by the use of the same material and methods of research.

NATURAL HISTORY OF CLASSICAL TIMES

We pass now to consider the natural history of classical times. The first well-defined epoch of natural history for which we have adequate written records was in the fourth century B.C., among the Greeks. All that was best in the natural history of that time is to be found in the writings of Aristotle and Theophrastus. The beginnings of zoölogy and botany are lost in the past, but all the previous accumulations of knowledge regarding animals and plants, clarified and reduced to system, are preserved by these two great naturalists. It is unlikely that the complete writings of Aristotle on animals have come down to

us, but we have sufficient fragments of his observations and reflections to form an estimate of what kind of observations he made and how he expressed himself in regard to them. The same may be said of Theophrastus in reference to plants. The writings of these two naturalists form a convenient starting point for discussing the natural history of antiquity. Aristotle represents the best of zoölogical inheritance combined with extensive personal observations; Theophrastus is a fitting representative of the botanical accumulations of his period. Aristotle observed plants as well as animals, but his writings on plants have been lost except so far as they are included in the work of Theophrastus. For clearness we must take up their investigations separately.

ARISTOTLE

The personality of a great man is always interesting and before giving attention to his writings and investigations in natural history we shall take a brief look at Aristotle the man. He was born at Stagira, in Thrace, 384 B.C., and died at Chalcis sixty-two years later. His father, a physician to the Macedonian king, Philip, took great care with his early education and is supposed to have encouraged him in the pursuit of scientific studies for which he had a natural taste. At the age of eighteen he became a student in the famous Academy of Plato at Athens and for twenty years lived in the intellectual atmosphere of Athens and the Academy. Subsequently he was one of the teachers of Alexander the Great, traveled in Greece and Macedonia, made important seaside studies in Mitylene, and returned to Athens where he set up a school of his own known as the Lyceum. At Plato's Academy he associated with Theophrastus, who was twelve years younger, and they formed a lifelong friendship. Theophrastus joined the staff of the Lyceum, and on the death of Aristotle assumed its management. The Will of Aristotle as a human document throws light on his character — it is a model of kindly consideration for his family and humanity for his slaves.

Some idea of his personal appearance may be obtained from

Fig. 4. It is a copy of a bas-relief found in the collection of Fulvius Ursinus (D. 1600), and was originally published by J. Faber. Its authenticity as a portrait is attested (1811) by Visconti, who says that it has a perfect resemblance to the head of a small bust upon the base of which the name of Aristotle is engraved. Portrait busts and statues of Aristotle were common in ancient times. The likeness most familiar to general readers is a copy of the head and shoulders of an ancient statue representing him with a draping over the left shoulder, an attractive portrait, showing a face of strong intellectuality. Its authenticity, however, is not so well established as that of the likeness shown in Fig. 4. The more recently discovered portrait of Aristotle (Fig. 5) with a beard is regarded by the best authorities as authentic. This conventional type of full beard is common in portraits of classical times (Theophrastus, etc.). Other portraits, believed to be those of Aristotle, represent him later in life with receding hair, and one exists in which his baldness is very extensive. He is described as short in stature, with spindling legs and small, penetrating eyes, and to have been, in his younger days, vain and showy in dress.

Fig. 4. — Aristotle, 384–322 B.C.: From a Bas-Relief Found in the Collection of Fulvius Ursinus. (Visconti, *Iconographie grecque.*)

He was early left an orphan, with a considerable fortune; and there are stories of early excesses after coming into his property. These charges, however, lack trustworthy support,

and are usually regarded as due to that undermining gossip which follows one holding prominent place and enviable recognition. His habits seem to have been those of a diligent student with a zest in his work; he was an omnivorous reader, and Plato called him the mind of his school. His large private library and his manner of living bespeak the conservation of his property rather than its waste in selfish indulgences.

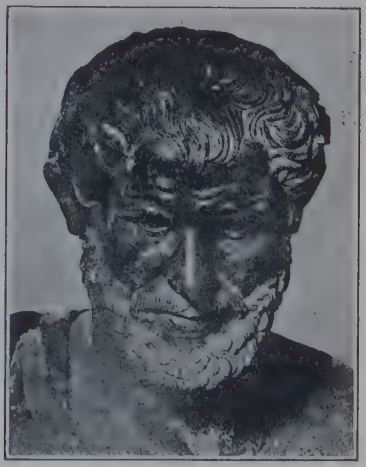

FIG. 5. — ARISTOTLE: FROM HERCULANEUM; PROBABLY FOURTH CENTURY B.C. (Singer, *Studies in the History and Method of Science*, Vol. 2. Reproduced by permission.)

His Position in the History of Science. The claims of Aristotle to consideration in the history of science rest chiefly on this — *he was the greatest investigator of antiquity*. A careful reading of his *Historia animalium* will show that he was no mere compiler — he was an investigating naturalist pursuing his subject by methods of personal observation, by broad comparison and by the use of reason.[2] We shall do well to cling closely to his contributions on the structure, the life history, and embryology of animals, keeping in mind that it is not his rank as a philosopher and as a writer on logic and other sub-

[2] The chief forerunner of Aristotle was the physician-naturalist, Hippocrates (460 B.C.), one of those who helped in establishing ancient science. Although his field of work was almost entirely medical, his general influence was great. He was one of the first to cast aside superstition and to base knowledge on experience. The method of Hippocrates, says Garrison, "was the use of the mind and senses as diagnostic instruments, together with his transparent honesty, and his elevated conception of the physician's calling." "Through Hippocrates, it was the chief glory of Greek medicine to have introduced that spontaneous, first-hand study of nature, with a definitely honest intention, which is the motive power of modern science." The famous Hippocratic oath is probably an older temple, or Asclepiad oath, and although we cannot attribute its origin to Hippocrates, its exalted tone represents his spirit. It is an important human document.

jects that is in question, but his contributions to natural history. The world has been so long accustomed to view him as a philosopher, in comparison with Plato and others, that to some it may seem unnatural to separate his work as a naturalist from his many other activities, although we are constantly doing so with other more recent writers. To estimate the position of Cuvier in comparative anatomy and palæontology it is not necessary to bring into prominence his belief in catastrophism or his position on the question of spontaneous generation of life and on organic evolution as expressed in his day by Lamarck. Alfred Russell Wallace's contribution to the geographical distribution of animals and to natural selection can be completely separated from his beliefs as a spiritist. Greek science was so intertwined with Greek philosophy that it is not easy to separate Aristotle's positive contribution to the knowledge of animals from his philosophical speculations, but only in this way shall we get a clearer picture of what Aristotle did to advance the knowledge of the structure and development of animals.

There is general agreement that Aristotle was a man of vast intellect, but he stands preëminent as a naturalist — this line of work was the most natural expression of his temperament and inclination. He was a pioneer in natural history who lifted the science of zoölogy to the high plane from which it declined in the hands of his successors.

Widely varying views have been expressed by naturalists and philosophers regarding Aristotle's merits. He has had his partisan adherents and his detractors. The extravagant praise of Cuvier impresses one as uncritical admiration expressing itself chiefly in rhetoric. George Henry Lewes, on the other hand, has emphasized the shortcomings of Aristotle by specific quotations, but has accompanied these with obviously insufficient citations to do justice to his merits. Lewes [3] says that Aristotle never made a discovery and in the nature of the case could not have made a discovery. This is ultra-critical, and had he quoted Aristotle's observations on the development of the chick and on the meta-

[3] *Aristotle — A Chapter from the History of Science*, 1864.

morphosis of insects, he would have weakened his contention. Charles Darwin said: "Linnæus and Cuvier have been my two gods though in very different ways, but they were mere schoolboys to old Aristotle."[4] While this statement is general, it evidently represents Darwin's impression from reading the natural history of the "old" Greek. Being himself a great observer, he was adept in recognizing in the works of another the marks of a fellow craftsman — the internal evidence of a great intellect employing observation in the field of natural history.

We shall get a one-sided view of Aristotle if we emphasize his errors and what he did not know — as Lewes has done. Much of his work in natural history — especially his seaside studies — is clearly based on observations extending over considerable periods of time, and his positive contributions to knowledge are of greater importance in determining the quality of his output than his desultory observations and unfinished fragments. Just as one gets a truer idea of Thackeray's rank as a writer by neglecting *The Yellowplush Papers* and basing judgment on an analysis of *Vanity Fair* and *Henry Esmond,* so with Aristotle, we shall arrive at a truer estimate of his position as a naturalist if we discriminate between his poorer and his better work.

At his best, Aristotle stands very high. No other observer of animals approached him until after the Renaissance. Pliny, the Roman naturalist (23–79 A.D.), was a compiler, not an original student. In comparison with the pioneer naturalists of the thirteenth century, Albertus Magnus, Thomas of Cantimpré, Bartholomæus, Aristotle was much more advanced and original. Not until the botanists, Bock and Valerius Cordus, in the first half of the sixteenth century, did he have his equal in methodical description, and, if we neglect the related but different kind of work of Malpighi, Swammerdam, and Leeuwenhoek of the seventeenth century, he had no superior up to Ray, the immediate predecessor of Linnæus. "On the whole, perhaps one will not err in repeating what has been said hundreds of times, that the

[4] *Life and Letters,* Vol. 2, p. 252.

works ascribed to Aristotle, and which, undoubtedly, were produced by him or by co-laborers under his direction, represent the most prodigious intellectual achievement ever connected with any single name." [5]

His Writings on Natural History. We shall get a better estimate of Aristotle as a naturalist by direct reference to his writings on natural history than in any other way. His chief treatises on natural history that have been preserved are — to use the Latin titles in place of the Greek — *De historia animalium, De partibus animalium,* and *De generatione animalium.* The treatises on motion and locomotion of animals are of minor importance. There is no agreement among scholars as to the order in which these works were produced, and the titles do not convey a correct impression of the subject matter. For illustration, *De partibus animalium* is not, as the title might imply, a treatise on comparative anatomy but rather on the uses of the parts of animals. Also, one would approach the *De generatione* expecting to find there the best and most specific account of the stages of development of animals, but in some instances better accounts of embryological stages are found in the *Historia animalium.*

Lewes considers the *De generatione* as Aristotle's masterpiece. He speaks of it as "an extraordinary production," saying, "No ancient, and few modern, works equal it in comprehensiveness of detail and profound speculative insight." Lones also says it is "one of the most remarkable works even written." The *Historia animalium* is notable for the great amount of information it contains, but the *De generatione* "astonishes the reader by its deep philosophical reasoning, and furnishes evidence of a powerful intellect, grappling with obscure embryological problems."

It appears to be the profound speculative insight of the author that influenced both of these writers, but it should be borne in mind that it is just this part of Aristotle's work that has depreciated the most in the face of modern advances. His theoretical considerations have long since become obsolete, while some of his observations remain as a part of the embryological

[5] Taylor, *The Mediæval Mind,* p. 181.

knowledge of today. Comparison of corresponding passages will show that the accounts of generation and development are fuller and clearer in the *Historia animalium* than in the *De generatione*. For illustration, the development of the chick, the description of the membranes surrounding it, and of the blood circulation are more specific in the *Historia animalium*.

Also, in the *Historia animalium,* Aristotle frequently refers to sketches saying, " for the disposition of these parts I must refer to my anatomical diagrams." In this treatise his observations on the development of animals stand in far less need of repair today than his philosophy of development.

The Historia Animalium. We shall now make a few summaries, based on a reading of the *Historia animalium,* and add a few brief citations from the same work. These latter will serve to convey an idea of Aristotle as an observer and to give the flavor of his writings on natural history. Fortunately, we have a complete translation from the original Greek by a zoölogist. D'Arcy Wentworth Thompson, professor of natural history in University College, Dundee, has rendered into English [6] the nine genuine books of this treatise and has increased the value of the translation by his comments as a zoölogist.

Aristotle's observations cover a wide range of topics, and the writing is evidently based on personal observations. His seaside studies on cephalopods (Sepia, Octopus, and others) give facts as to structure, habits, geographical distribution, and development. " It is often held that Aristotle devoted himself to biology as an old man's recreation," but Thompson has brought forward evidence, based on the geographical mention of places, to show that Aristotle did his work in natural history in middle life on the island of Lesbos, where he spent three years before he went to Macedonia to take part in the education of Alexander. In his natural history, references to places in Greece proper are very few, but there is frequent mention of places in and around Mitylene. In specific cases he mentions animals of this region

[6] The English translation is a volume of about 340 octavo pages exclusive of the footnotes (455 pages including notes and sketches).

which do not occur in Greece proper. Thompson concludes that his natural history studies "preceded his more strictly philosophical works," and accordingly exerted an influence on his philosophy.

It is well known that he observed the preoral position of the yolk-sac of the developing Sepia; furthermore, he refers to drawings of it — which, unfortunately, together with his other anatomical sketches have been lost. It appears from numerous references in the *Historia animalium* that Aristotle had prepared a volume of anatomical sketches. In several instances he anticipated modern discoveries, as in the case just mentioned, and in his description of the modified arm of the male cuttlefish into a long whiplash, a structure which is transferred to the mantle-cavity of the female for fertilization. Supplementary notes of Aristotle cited by Thompson, and probably not known to Lewes, show that Aristotle understood the purpose of this structure although Lewes attempts to show that he did not.

Speaking of his work on the cephalopods as a whole, Thompson says: "This is far more than a mass of fragmentary observations gleaned from fishermen. It is a plain orderly treatise on the ways and habits, the varieties, and the anatomical structure of an entire group."

Aristotle's discovery of the placenta-like connection of the young in the oviduct of the smooth dogfish (Mustelus lævis) could have been made only by an experienced anatomist, and this work excited the admiration of Johannes Müller, who rediscovered the facts about 1840.

In reference to crustacea, his description of crayfish, crab, shrimp, etc., as to appendages and general appearance is good, and he also gives clear evidence, by descriptions of internal anatomy, of having practiced dissection. In the crayfish he mentions the chitinous teeth within the stomach, the alimentary canal, the reproductive organs, etc. Even summaries of his observations will become too voluminous for our space, and we shall give only a few citations to show the flavor of his writings.

His simple, direct statement of the metamorphosis of insects

is as follows: "The so-called psyche or butterfly is generated from caterpillars which grow on green leaves, chiefly leaves of the raphanus, which some call crambe, or cabbage. At first it is less than a grain of millet; it then grows into a small grub; and in three days it is a tiny caterpillar. After this it grows on and on, and becomes quiescent and changes its shape, and is now called a chrysalis. The outer shell is hard, and the chrysalis moves if you touch it. It attaches itself by cobweb-like filaments, and is unfurnished with mouth or any other apparent organ. After a little while, the outer covering bursts asunder, and out flies the winged creature that we call the psyche or butterfly. At first, when it is a caterpillar, it feeds and ejects excrement; but when it turns into the chrysalis it neither feeds nor ejects excrement." [7]

EMBRYOLOGY IN THE HISTORIA ANIMALIUM

In animal embryology any connected results require careful observation of small details, and in this domain Aristotle shows not merely an inquiring mind, but an investigating spirit willing to spend time on observations often extending over months. With different animals he deals with breeding habits, time of egg-laying, appearance of the eggs, and the stages in the formation of the animals. An abridged account of his observations on the development of birds follows: "With the common hen after three days and three nights there is the first indication of the embryo; with larger birds the interval being longer, with smaller birds shorter. . . . The heart appears like a speck of blood. This point beats and moves as though endowed with life, and from it two vein-ducts with blood in them trend in a convoluted course, and a membrane carrying bloody fibres now envelops the yolk leading off from the vein-ducts. A little afterwards the body is differentiated, at first very small and white. The head is clearly distinguished and in it the eyes swollen out to a great extent. . . . At the outset the lower portion of the body appears insignificant in comparison with the upper portion. Of the two

[7] *Historia animalium*, p. 551a.

ducts that lead from the heart, the one proceeds towards the circumjacent integument, and the other, like a navel-string, towards the yolk. . . ."

"When the egg is now ten days old, the chick and all its parts are distinctly visible. The head is still larger than the rest of the body, and the eyes larger than the head, but still devoid of vision. The eyes, if removed about this time, are found to be larger than beans, and black; if the cuticle be peeled off them there is a white and cold liquid inside, quite glittering in the sunlight, but there is no hard substance whatsoever. . . . At this time also the large internal organs are visible, as also the stomach, and the arrangement of the viscera; and the veins that seem to proceed from the heart are now close to the navel. From the navel there stretch a pair of veins; one towards the membrane that envelops the yolk . . . and the other towards the membrane which envelops collectively the membrane wherein the chick lies, the membrane of the yolk, and the intervening liquid. . . . On the tenth day the white is at the extreme outer surface, reduced in amount, glutinous, firm in substance, and sallow in color."

"The disposition of the several constituent parts is as follows: First and outermost comes the membrane of the egg, not that of the shell, but underneath it. Inside this membrane (the allantois) is a white liquid; then comes the chick, and a membrane round about it (the amnion), separating it off so as to keep the chick free from the liquid; next after the chick comes the yolk, into which one of the two veins was described as leading, the other one leading into the enveloping white substance. . . ."

"About the twentieth day, if you open the egg and watch the chick, it moves inside and chirps; and it is already coming to be covered with down; when, after the twentieth day is past, the chick begins to break the shell. The head is situated over the right leg close to the flank, and wing is placed over the head. . . ." He then tells of hatching and disappearance of the yolk. Ten days after hatching, "if you cut open the chick, a small remnant of yolk is left in connection with the gut."[8] This

[8] *De historia animalium*, p. 560b.

shows that in description Aristotle is methodical, straightforward, not diffuse, and that he has well assimilated his observations. In many instances he engages in broad comparisons.

Aristotle's view in reference to animals was comprehensive; as Hertwig says: "He founded zoölogy on broad lines as a universal science, since anatomy and embryology, physiology, and classification find equal consideration." And yet, not quite equal consideration — he subordinated classification to the more important features of structure, development, and physiology, which he was discerning enough to recognize as of greater worth. In his temper he is more closely allied to the morphologists, like Cuvier, than to the classifiers, like Linnæus. With Aristotle, classification is more incidental and is an outgrowth of his studies of structure and development. He mentions about five hundred species of animals, "but since he does not mention some very well-known forms, like the badger, the dragon-fly, etc., we can assume that he knew others, but did not regard it necessary to give a catalogue of all forms known to him, and he mentions them only when he wishes to refer to habits and certain structural conditions found in them."

Classification. A brief summary of Aristotle's classification will be in order. He is satisfied with two categories — the γένος, or group, and the εἶδος, or species. He does not employ terms marking off families, tribes, etc. His group-designation genos corresponds not to the genus but to the class of modern classification. He makes eight classes of animals of which four are blood-containing, and correspond to vertebrates. Mammals (in which group, with discernment he includes whales, porpoises, etc.); birds; oviparous quadrupeds; and fishes. A second group of four classes embraces our invertebrates, and are designated by Aristotle as "bloodless." These are: Mollusca (the cephalopods); crustacea; insects; and animals with shells (including our shelled mollusks).

In connection with his Lyceum he had an extensive botanical garden, containing exotic and domestic plants. Aristotle's writings on plants are lost, and it was Theophrastus who per-

petuated that knowledge of plants which was possibly a product of the whole great school, various advanced students, assembling and systematizing information under the supervision of Aristotle and Theophrastus.

Evolution. In the philosophical consideration of animal life, Aristotle possibly glimpsed the germ of the idea of evolution. As Osborn has shown in his volume, *From the Greeks to Darwin,* he certainly believed in a complete gradation from the lowest to the highest organisms, and that man is the highest point in the scale. But, as previously stated, most of his philosophical speculations regarding animal life and development have become obsolete, and we are to keep in mind that these speculations are negligible when estimating his standing as a naturalist. That part of his work that endures is his positive observations. In the face of conflicting testimony regarding his rank, we should fix attention only on these. It is significant that adverse testimony comes chiefly from those who have no first-hand acquaintance with his writings on animals.[9] Aristotle had one of the best equipped minds of all time, and his contributions represent the highest level reached by natural history before the sixteenth century. He made a direct appeal to nature for his facts and based his natural history on observations of structure, development, and habits of animals. His influence was projected far beyond his time, and, in the revival of scientific learning in the Middle Ages, the return to Aristotle's writings marked an advance.

We should not completely overlook the mistakes and inconsistencies in the writings on animals that are attributed to Aristotle. There is often a curious mixture of profound observation with trivial matter and obvious error. The work is so uneven that Huxley has suggested that, since he taught *viva voce,* the remnants of his zoölogical writings accessible to us may possibly be founded on the notes of some of his students. At all events,

[9] The same can be said regarding the estimates of the rank of Theophrastus. Study of the observational contributions of these naturalists results in restoring them to their rightful place in the history of science.

it is highly probable that the scientific work ascribed to Aristotle is a composite product of himself and his disciples. If there be anything at all in the argument from internal evidence, we are justified in throwing doubt upon some parts of the work as being from the hand of Aristotle. The mixture of the very good and well assimilated with the weak and the foolish betrays another hand, as in a masterpiece retouched by an inferior artist. From what we know of the history of manuscripts and of the close union in which the members of the Lyceum worked, it seems likely that his scattered discourses were combined by others and that his notes and outline sketches were changed in the process of editing. In fact, what we now know as the writings of Aristotle and Theophrastus, considered as a whole, were the product of the Lyceum — the work of many hands, some more competent than others, rather than the individual work of either of the masters, though some parts are undoubtedly of their authorship. For illustration, as pointed out by Thompson, Aristotle's account of the vascular system is "remarkable for its wealth of detail, for its great accuracy in many particulars, and for its extreme obscurity in others." There are also attached to this account some traditional statements in reference to the heart and vascular system completely at variance with what we know of Aristotle's standards. He was *par excellence* the "Greek philosopher who clearly discriminated discovery and disputation — science and dialectics — the knowledge of a definite subject and discussions of anything whatever from opinion and authority." But, from lack of conclusive evidence, we are brought to an *impasse* and "we may as we please ascribe the defects to imperfect dissection, to a corrupt or mutilated text, or possibly to the persistence of archaic and traditional views in regard to the heart." [10]

The "note-book theory" is usually accepted by those who have labored long over Aristotle's writings. According to Gomperz we have nothing as it was left by Aristotle; his manuscripts, with others of the Lyceum, were bequeathed to Neleus by Theo-

[10] Thompson, p. 513a.

phrastus; ultimately they went to Rome (not to Alexandria). The fate of Aristotle's library has been the subject of much controversy; the books were carried by Neleus to Scepsis, where it is said they were concealed underground to escape "the literary cupidity of the Kings of Pergamos." [11] These mouldy manuscripts were afterwards copied and edited. The beauty of Aristotle's discourse has remained as a tradition; in ancient literature he was spoken of as a most eloquent, convincing, finished, and ready speaker, but the writings on animals attributed to him that we now possess have a very constrained style devoid of literary grace. But, outside all this, there is enough good strong work in the *Historia animalium* to establish Aristotle's place among the greatest observers.

THEOPHRASTUS

Before his death Aristotle handed over to Theophrastus (372–288 B.C.), the Lyceum together with his library, including the manuscripts of his writings. At the period of its greatest prosperity, the Lyceum enjoyed an attendance of two thousand students, — a very large school even by our modern standards. Theophrastus was much occupied in administrative duties. He did not travel, as did most of the scholars of his day; but the Lyceum gardens were extensive, and owing to the financial assistance of one of the wealthy citizens of Athens, they were provided, as we have said, with exotic as well as with domestic plants. Also some of the students traveled, sent back plants for the garden, and accumulated information regarding plants of foreign countries, so that Theophrastus was able to extend his horizon of botanical knowledge.

An unbiased examination of the writings of Theophrastus will convince one that he merits the title of "Founder of scientific botany." It has become the fashion to neglect the writings of early naturalists and because of a lack of knowledge to presume that since they were written so long ago they must therefore be primitive and of little value.

[11] Article Libraries, Ency. Brit., Eleventh edition.

Like most writers of his time, he treated of a large number of subjects, and two hundred twenty-seven treatises have been ascribed to him. But, as "the author of the oldest distinctly botanical treatise that is extant, the place of Theophrastus is unique and invites to careful consideration." In the time of Tournefort, Linnaeus, and Haller, he was generally recognized as a scientific botanist. Haller with concise and well-considered words said of him "Primus verorum botanicorum" — in point of time the first true botanist. It was only in the last half of the nineteenth century that a supercilious tone came to be used in reference to his rank and that by those unacquainted with his writings.

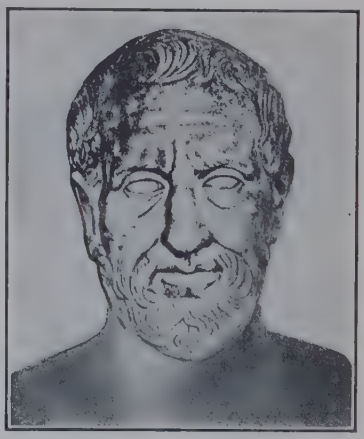

FIG. 6. — THEOPHRASTUS, 372–288 B.C.: FROM VILLA ALBANI; PROBABLY SECOND CENTURY A.D. (*Studies in the History and Method of Science*, 1921.)

The two botanical works of Theophrastus are *The History of Plants*, and *The Causes of Plants*. Edward Lee Greene has made a thorough study of Theophrastus and of his principal work, the *Historia plantarum*. The History, the more important of the two, was published in English in 1916 under the title *Enquiry into Plants* (Loeb Classical Library). It is not a very voluminous work; in the English translation just referred to there are about three hundred ninety-two duodecimo pages. In style it is condensed, like lecture notes, and therefore lacks literary merit. At the same time it gives a methodical summary of facts about plants as to root, stem, branch, seed, flower, and fruit, and in that sense is a scientific treatise. Theophrastus mentions some five hundred different plants — employing, indeed, a larger number of Greek words to designate them, some of the names being synonymous.

The *Enquiry into Plants* is not, however, merely an enumeration of different kinds of plants, but, as we have just said, a comparative study systematically exhibited in condensed style. The titles of the nine books into which it is divided will afford some idea of its scope. 1. Of the parts of plants and their composition. Of Classification. 2. Of Propagation, especially of Trees. 3. Of Wild Trees. 4. Of the Trees and Plants special to Particular Districts and Positions. 5. Of the Timber of Various Trees and Its Uses. 6. Of Under-Shrubs. 7. Of Herbaceous Plants, Other than Coronary Plants, Pot-Herbs and similar Wild Herbs. 8. Of Herbaceous Plants; Cereals, Pulses, and "Summer Crops." 9. Of the juices of Plants, and of the Medicinal Properties of Herbs.

Theophrastus' *Historia plantarum* is a series of concise, crisp conclusions based on extensive observation. Aristotle's *Historia animalium* is also a condensed summary of results. The *Historia animalium* reads better than the *Historia plantarum* — it is fuller in specific details and gives the impression of a greater intellect back of the writing.

Theophrastus was an observer of the life histories of plants, not merely a desultory collector of sayings and traditions about them; he was an investigator of their structure, their growth in reference to soil, etc. As E. L. Greene says: "There are chapters in the *Historia plantarum* that are crowded with facts about seeds, seeds in process of germination, young seedling plants and older ones, observations on this plant and that shrub as they appear in spring, summer, autumn, and winter, that, all being considered, we should have wondered greatly how this most untraveled and sedentary of the great philosophers had gained all this minuteness of knowledge about the little things of plant life, had we not been informed concerning this great garden in the midst of which he dwelt, taking his daily recreation along its paths, and among its seed beds, and within the bounds of which, obedient to his last request, they buried him." [12]

[12] *Landmarks*, p. 58.

Greene's rather impressive summary enumerates seventeen "items or elements, of universal botany of which Theophrastus appears to have been the discoverer and first promulgator." These are too many and too extensive to be reproduced here in their entirety, but we make note of five: "(6) By never speaking of calyx and corolla as peculiar and separate organs, but always referring to their parts as leaves merely, it is evident he regarded the flower but as a metamorphosed leafy branch; to which forgotten Theophrastan philosophy of the flower neither Goethe nor Linnæus had but returned, when each supposed himself the discoverer of a new anthogeny." "(7) He divided the plant world into the two subkingdoms of the flowering and the flowerless." "(11) He was the first to use the term fruit in the technical sense, as applying to every form and phase of seed encasement, seed included; and gave to carpology the term pericarp." "(12) He classified all seed plants as (a) angiospermous, and (b) gymnospermous." "(17) Theophrastus, with natural vision unaided by so much as the simplest lens, and without having seen a vegetable cell, yet distinguished between parenchymatous and prosenchymatous tissues; even correctly relating the distribution of each to the fabrics of pith, bark, wood, leaves, flowers, and fruits."

On the other hand, Julius Sachs — whose history of botany holds an acknowledged place, though it deals only with the period from the revival of botany in 1530 — speaks slightingly of Theophrastus. Apparently, he bases what he has to say of Theophrastus on the demerits of his philosophy. As remarked in our consideration of Aristotle, this is a common source of confusion, and the rank of both Aristotle and Theophrastus should be based on their positive contributions. E. L. Greene says of Theophrastus, "When a man has firmly laid the foundations of a science, and then added the suggestions of almost the whole superstructure, what faintest shade of pertinency can there be in asking what his philosophical doctrines were? As reasonably might one leave any scientific work, alive with new

facts, quite unexamined because its author's philosophy was that of a school unpopular, or his creed unorthodox." [18]

SUMMARY

The first well-defined epoch of natural science was in the fourth century before Christ among the Greeks. Aristotle and Theophrastus were two master-minds. They were both original observers and methodical in their treatises on animals and plants. Aristotle was the greater intellect of the two. Their product has been undervalued by those modern writers who have possessed no first-hand knowledge of their works. This makes it necessary to correct many misconceptions. A reading of the *Historia animalium* shows that Aristotle was an original observer, contributing many positive observations to zoological science — while his theoretical considerations have become obsolete. Theophrastus was a scientific botanist studying plant structure, growth, and distribution. Ecology is often thought of as decidedly a recent subject, but Theophrastus did something in that line by observing association of plants in different habitats, swamps, fields, ponds. He founded botany as a science. He did not — as often stated — give chief attention to the medical properties of plants. Both Aristotle and Theophrastus made experimentation the basis of science.

[18] *Landmarks*, p. 142.

CHAPTER III

GREEK SCIENCE IN ALEXANDRIA

It has been pointed out in the previous chapter that the Greek mind of classical times was of a superior type; the intellectual workers of Greece were among the most brilliant and productive of all antiquity; they exhibited originality and creative powers. No sooner, however, had Greek science attained a high degree of development on its native soil, than great political changes forced its transplanting to a far-away country. Even in Aristotle's lifetime the center of Greek science and culture passed from Athens to the newly-founded city of Alexandria in Egypt. This momentous change was due to the conquest of Greece by Philip, the aggressive king of Macedon, and his ambitious son, Alexander, the founder of the Macedonian Empire.

The form of political union in Greece at this time was one that did not tend to permanency. The political unit was the city-state, the cities being united into a loose federation, which allowed to its members a large degree of local freedom but provided little unity as a nation. In the face of invasion the federation lacked the resisting power of a unified nation, and thus Greece became an easy prey to Philip and Alexander. These Macedonian rulers succeeded in subjugating Greece about 330 B.C. The conquest of Greece was only one step in the larger plan of extending widely the dominion of Macedon to the east and to the southwest. The victorious armies marched from Asia Minor into Egypt, and conquered Persia in the east. After the conquests of Philip and Alexander, the history of Greece was merged in that of the Macedonian Empire. When Greece lost her national independence, she also lost her intellectual leadership; but her culture, although its active center was trans-

ferred to a new environment, continued to exert its influence for several centuries as the dominating force in western civilization.

ALEXANDRIA FOUNDED

In 332 B.C., Alexander set up a city in Egypt on the south shore of the Mediterranean, to the west of the mouth of the Nile. This city was intended to take the place of Tyre, which Alexander had destroyed on account of its stern resistance to his triumphal march. The new city, Alexandria, gave communication with the rich Nile valley and was favorably situated in regard to the chief trade-routes of the western world. On account of its geographical position it came into commercial relations with all nations lying about the Mediterranean, and at the same time formed a connecting link with the wealth and the products of the East. It rapidly developed into a large commercial center.

On the death of Alexander, 323 B.C., the Macedonian Empire was partitioned among Alexander's generals, and Egypt fell to the share of Ptolemy Soter — a large-minded man who was a patron of science and learning. Under him and his immediate successors, the great library of Alexandria was accumulated and science was promoted along with other branches of learning. As the prestige of Athens declined, men of scholarly tastes, and especially young men of ambition — eager for learning — wended their way to Alexandria for study. For several centuries science and learning made its abode there though during this period science declined, and Alexandria obtained the distinction of having been the culture-center of the western world for a longer period than any other city. Here science and learning were essentially Greek. Most of the men who attained marked eminence were of Greek extraction, as Euclid in geometry, Archimedes in mathematics and physics, Herophilus and Erasistratus in anatomy. The Greek influence was so strong that Attic Greek became the spoken language of commerce as well as of science, and spread widely in the East. In population, the city was

cosmopolitan, but the majority of the people were Jews, Egyptians, and Greeks. The Jews, inhabiting a quarter of their own, were so numerous that Alexandria was the largest Jewish city of antiquity. The Greek language became so universal that the Jews had the Hebrew scriptures translated into Greek — and thus arose the Septuagint.

THE PTOLEMIES ENCOURAGE SCIENCE AND LEARNING

The Ptolemies, who were largely responsible for the ascendency of Alexandria, constitute a dynasty of Macedonian kings, fourteen in all, who ruled in Egypt from 323 until 30 B.C. — when Alexandria fell under Roman control. The first of the line was Ptolemy Soter, the trusted general of Alexander, and who first became Satrap under a nominal king, soon, however, gaining independence. He was a man of progressive ideas. He established in Alexandria a great institution, under the title of the *Museum*. Its buildings were on a hill sacred to the Muses, from which circumstance it derived its name. This institution was not a museum in the modern sense of the word, but an intellectual center comparable to a great university. Inasmuch as science was cultivated there, it has been spoken of as an Academy of Sciences. The Museum was established on liberal lines and provided with funds for the encouragement of science and learning. It came to include rooms for investigators and students, laboratories, collections of animals and plants, and an extensive collection of manuscript rolls. The library well started by the first Ptolemy was greatly increased through the efforts of Ptolemy Philadelphus. There were two large collections of reading matter — one at the Museum and the other at the Serapheum. This Alexandrian Library was probably the largest one of antiquity, and is notable as among the first large public libraries. It was not quite the first; there had been an extensive library at Babylon, which was open to the public, and also one at Pergamos, and large private libraries existed in Greece.

THE ALEXANDRIAN LIBRARY

Ptolemy Philadelphus, son and successor of Ptolemy Soter, was an enthusiast for Hellenic culture and fostered Greek science. All Greece and Asia Minor was ransacked for books, and his successor "is said to have caused all books brought into Egypt by foreigners to be seized for the benefit of the library, while the owners had to be content with receiving copies of them in exchange." It is commonly believed that the collections reached the number of seven hundred thousand rolls — the manuscripts at the Museum being much in excess of those at the Serapheum. The oft-repeated story that the books of Aristotle were acquired by the second Ptolemy lacks confirmation. As related in the previous chapter, these books were bequeathed by Theophrastus to Neleus, whose heirs concealed or buried them in a cellar at Scepsis to keep them from the acquisitive kings of Pergamos.

It was a great calamity for scholarship when the Alexandrian Library was destroyed. It underwent several stages of dissolution, and the entire blame is not to be laid to the Saracens, who, under Caliph Omar, captured Alexandria in 642 A.D. The Saracens merely completed the destruction of a depleted library which had suffered from fire — when, in 47 B.C., Cæsar set fire to the fleet in the harbor of Alexandria — and, later, by other depredations. "It is very possible that one of the libraries perished when the Brucheum quarter was destroyed by Aurelian, A.D., 273." Also "in 389 or 391 an edict of Theodorus ordered the destruction of the Serapheum (temple of Serapis), and its books were pillaged by the Christians." [1]

In connection with the Library were "Scriptoria," offices for copying books, and through their agency manuscripts were multiplied which gave rise to a sort of publishing business. The "Alexandrian Editions" were highly prized and were recognized as the best of the time.

[1] Article Alexandria, Ency. Brit., Eleventh edition.

GENERAL SCIENCE AND MEDICAL STUDIES

All branches of learning were encouraged at the Museum, not merely science but language and literature as well, but while we bear in mind the comprehensive character of the intellectual movement, we must confine our attention here to the development of the sciences. Astronomy, Geography, Mathematics, and Physics had numerous devotees and progressed rapidly. Althought natural history was encouraged, it does not seem to have taken a leading part — unless we consider the closely related medical subjects as a part of it. The medical school of Alexandria became very famous, and young men came from all parts of the world to devote themselves to several years of preparation for the practice of medicine.

Medical Studies. Several subjects embraced in the medical course are, indeed, closely related to natural history, such as studies of animal structure, development, physiology, and of plants. The physiology of the time is of no consequence, but studies of the structure of the human body, and of related animals took a forward step. The names of Herophilus and Erasistratus stand out as the most notable of the founders of the Alexandrian school of anatomy and medicine. As students of anatomy, they are related to the morphologists. They are said to have inaugurated dissection, but this is to be taken with qualifications. Aristotle mentions one of his forerunners by name — Alcmæon (500 B.C.) — as a dissector and as one who urged upon others the necessity of dissection of the human body. Dissection is also a method of comparative anatomy and applies to animal dissection as well as to that of the human body. Aristotle, in the *Historia animalium,* several times refers to his volume of animal sketches, and we have abundant evidence that he was a comparative anatomist on broad lines. Herophilus and Erasistratus revived dissection, and, under more favorable conditions than had previously existed, extended it to the human body. Dissection of the human body was authorized at Alexandria in early days, but it was afterwards proscribed as it had been in Greece

and other countries. Celsus says Herophilus and Erasistratus were provided with condemned criminals, and the best authorities on Greek medicine give credence to the statement that vivisection was practiced on these criminals. At any rate, the science of anatomy advanced under these two men and constitutes one of the recognized products of the Alexandrian school.

HEROPHILUS AND ERASISTRATUS

That Herophilus and Erasistratus lived in Alexandria in the time of Ptolemy Soter seems to be established. Little is known regarding these two men, except that they were both devoted to researches in anatomy, and Erasistratus, in particular, attained fame as a medical practitioner. They were in a measure rivals. Herophilus (ca. 335–280 B.C.) having been educated under Praxagoras, a celebrated representative of the school in Cos, was an upholder of the doctrines and traditions of Hippocrates. Erasistratus (ca. 300–260 B.C.), on the other hand, was educated in a rival school. Both prepared treatises on anatomy and other medical subjects, of which there remain no complete textual records. Fragments of Herophilus are preserved in various ancient works, and Galen gives a number of citations from the writings of Erasistratus for the purpose of controverting them. The citations relate chiefly to medical practice, such as venesection, etc. The titles of their written works are mentioned in antique literature, both by medical men and by non-medical writers. The principal work of Herophilus was apparently his Anatomy, which is considerably quoted by Galen. Finlayson has shown that both men certainly wrote on anatomy. He gives the names of more than twenty writers containing citations of Herophilus and Erasistratus. Among the medical writers are Galen, by far the most important source of information, and Dioscorides; and among classical authors, not physicians, are Pliny, Plutarch, etc. A complete list of their anatomical discoveries would be difficult to compile, as well as tedious, but Herophilus is commonly credited with the discovery,

or with the first known description, of the torcular Herophili, the calamus scriptorius, the duodenum, and the lacteals. He was so much devoted to anatomical studies that he is said to have dissected seven hundred bodies. Fallopius called him "the evangelist of anatomists." In a sense, he was the inventor of pathological anatomy, being the first in recorded history "to open the bodies of men after death in order to ascertain the nature of the fatal malady."

Regarding Erasistratus there is also a scarcity of biographical facts; Pliny says that he was Aristotle's nephew, but that is not confirmed by any other writer. He stands, however, in intellectual relationship with Aristotle, since one of his teachers, Metrodorus, was the third husband of Aristotle's daughter, Pythias, and another preceptor was Theophrastus. Galen wrote in strong opposition to some of the medical views of Erasistratus. Finlayson says: "Erasistratus pursued anatomy with such enthusiasm that, in later years, when he had withdrawn from practice, he resumed anatomical studies, and made many fresh discoveries, correcting the errors of his earlier views. In particular, he described the lacteals more fully than Herophilus had done; and he pursued the anatomy of the human brain."

Since the question is often raised whether the ancients engaged in experiment, it is worth while to note that Erasistratus is credited with devising the first crude respiration calorimeter, a jar in which he kept fowls, weighing them and their excreta, after feeding and completed digestion. (Garrison, p. 89.)

The death of Erasistratus was voluntary; being afflicted in old age with an incurable ulcer of the foot, he drank hemlock and passed away with composure.

SUMMARY

Following the conquest of Greece by the Macedonians the active center of Greek science and culture was transferred from Athens to Alexandria. The early Ptolemies who ruled in Alexandria were patrons of learning and science; they established a

university under the name of the Museum, and accumulated the great Alexandrian Library. The science of the Alexandrian school was thoroughly Greek in character. Literature, ecclesiastical studies, and general science were promoted. Natural history did not take a leading rank, but the medical school was famous, and anatomy, which is closely allied to natural history, was ably represented by Herophilus and Erasistratus.

CHAPTER IV

NATURAL HISTORY DURING THE ROMAN PERIOD

According to the will of Ptolemy X, the city of Alexandria passed formally under the jurisdiction of Rome in the year 80 B.C., but was not completely subjugated until 30 B.C. The city still preserved its commercial importance, and an active intellectual life continued at the Museum and the Library, but in a somewhat changed direction. The medical school maintained its position, but no great naturalists arose, and, as the years went by, Alexandria became a seat of Christianity and of theological learning. The genius of Rome swept over the Mediterranean world bringing in its wake great changes in the spirit of the time. The Romans were a people of practical turn of mind, devoted to government, military affairs, and civic aggrandisement. Vitruvius, the architect, represented a new line of scientific endeavor, but the study of nature languished. The Romans were not a creative people, and Rome with all her worldly glories never became a true culture-center. In the four centuries of the existence of the Western Empire, no great scientist of Roman extraction arose. Some Roman writers however showed an incidental interest in nature or a love of nature, as Virgil, Varro and others. Pliny, the naturalist, the most famous writer on natural history of the time, was a Roman, but Galen and Dioscorides, whose recognition is deservedly greater, were both Greeks who lived in Rome.

As Breasted says: "There was now a larger educated public in Rome than ever before, and the splendid libraries maintained by the State were open to all. Authors and literary men were liberally supported by the emperors. Nevertheless, even under these favorable circumstances, not a single genius of great creative imagination arose. Just as in sculpture and painting, so

now in literature the leaders were content to imitate or copy the great works of the past." In science, where originality requires greater personal independence, the situation was even worse, and productivity had ceased — Romans with any inclination towards science were content to be mere compilers.

PLINY'S NATURAL HISTORY

Pliny was not a great naturalist like Aristotle; nevertheless, his *Natural History* had a strong popular appeal, and it was one of the most famous and widely read books of his time and of the Middle Ages. Notwithstanding the great length of the *Historia naturalis,* it was one of the few ancient works that was repeatedly copied and has been preserved to us in its complete form. The book, as Thorndike says, was one to delight the Middle Ages; it was full of anecdote, included the popular superstitions, and was not too heavy for the general reader.

Pliny the Elder, (23–79 A.D.), was a Roman general with a love of books and an inclination for literary pursuits. He gave his nights to reading and literary composition, and his days to the service of the government. He lost his life in the eruption of Vesuvius which destroyed Pompeii in 79 A.D. During his life he had published, by the year 77, the first ten books of his *Natural History,* and at the time of his death, was engaged in revising the rest of this work. His nephew, Pliny the Younger, so well known as a letter writer, gives a good account of his uncle's industry, his methods of life, and the circumstances of his death.

Pliny's book is encyclopædic in range, and the title, *Natural History,* is too limited. In thirty-six "books" he treats of the world, the heavens, planets, geography, man, his discoveries and inventions, animals, plants, minerals, the history of medicine, remedies, and other miscellaneous topics. It might be called the *Miscellanies* of Pliny, using the word in a wider sense than usual. Thorndike says, "It is an attempt to cover the whole field of science; *rerum natura* is its subject."

To give an idea of the dimensions of the book, — the fine

Latin edition from the press of Nicolas Jenson, Venice, 1472, has seven hundred six printed folio pages; the translation of Pliny into English by Bostock is printed in six volumes, and with

FIG. 7. — PLINY, THE ELDER, 23–79 A.D. (Jardine, *The Naturalist's Library.*)

the notes aggregates 3104 octavo pages, of which about two thousand pages are devoted to the text proper.

The dedication to Titus Vespasian (later Emperor) constitutes book 1, and there are thirty-six books of the text. In the dedication Pliny says: "I do not write for very learned people. . . . My road is not a beaten track, nor one that the mind is much disposed to travel over. There is no one among us (the Romans) who has even attempted it, nor is there any one individual among the Greeks who has treated of all the topics. . . . I have included in thirty-six books twenty thousand topics, all worthy of attention . . . gained by the perusal of about two thousand volumes . . . especially of one hundred select authors; and to these I have made considerable additions

of things which were either not known to my predecessors or which have been lately discovered."

The wide range of topics will be seen by an abbreviated summary of the titles of the "books." Book 1, Preface and dedication; Bk. 2, The world, the (4) elements, and the heavenly bodies; Bks. 3–6, An account of the geography of different countries, including the inhabitants, tribes, etc.; Bk. 7, Man and his inventions; Bks. 8–11, Animals; Bks. 12–21, Trees, plants, flowers; Bk. 22, Garlands and medicines; Bks. 23–32, Medicines, medical authors, and magic; Bks. 33–37, Gold, silver, copper, lead, marbles, gems, and stones, Bk. 35, On painting, colors, and painters.

In natural history, strictly speaking, he devotes more space to plants than to animals, and seems to understand them better; his knowledge of animals is very remote. Seldom does he quote Aristotle directly but gives in his own words an epitome of his reading. The writing of Aristotle in the *Historia animalium* is strong, well assimilated, and much of it evidently based on original observation. The feeling produced by reading the two authors is very different. One perceives that Aristotle is a master-mind, dealing with subjects with which he is familiar from personal contact. Pliny writes of animals like an amateur, unacquainted with his material at first-hand, paraphrasing the words of another with some essential omissions; and in the paraphrasing the writing loses its originality and strength. The most significant observations of Aristotle are often overlooked; his notable seaside discoveries about sepia and other cephalopods, his anatomical findings about the crayfish, and other crustacea, as well as other parts of the *Historia animalium,* are either missed altogether as the placental connection of the embryo of the smooth dogfish shark, or paraphrased too generally and vaguely as in the observations on embryology. Pliny undertakes to epitomise Aristotle's account of the development of the chick, but the way in which he does it and the elision of some of the most important points make it lose its strength. The following quotation from Pliny when compared with Aristotle on the same

subject (p. II, 534) will show the contrast. "In the middle of the yolk of every egg there is what appears to be a little drop of blood. This is supposed to be the heart of the chicken, it being the general belief that it is formed the first in every animal. . . . The body of the animal itself is formed from the white fluid in the egg; while the yellow part constitutes its food. The head of every kind, while in the egg, is larger than the rest of the body; the eyes, too, are closed, and are larger than the other parts of the body. . . . On the twentieth day, if the egg is shaken, the voice of the now living animal can now be heard in the shell." Here there is a characteristic contrast; the subject is vaguely understood by Pliny and its best parts not appreciated. Aristotle's exact description of the embryonic membranes, etc., is lost. Aristotle is specific and full of meaning — his account based on actual observation; Pliny is general, his epitome vague and inexact.

In treating of animals, as in many other connections, Pliny is most of all interested in curious questions: — "Who first used goose liver for food? Who first used the pea fowl for food? When was the eagle first used as the emblem of the Roman Legion?" etc. In his treatise a large amount of attention is given to the virtues of plants, and to remedies derived from animals, plants, and minerals; — thirty-six remedies from the tortoise, etc. Considerable attention is given to medicine and medical writers, and a brief history of medicine is included in the work. Among twenty thousand topics it may appear invidious to pick out one or two, but at least that is better than to pick out none. The fact of the matter is that Pliny lacks discrimination; he is an indiscriminate collector of anecdotes, sayings, traditions, and citations from earlier writers. His extensive references to ancient writers constitute the best part of his book; in a measure he represents all ancient literature, and many writers would be unknown except for his references. His encyclopædia also well represents the decline of science after Aristotle. With the notable exceptions of Galen and Dioscorides, men were content to be compilers in the field of science.

As we have said, the influence of Pliny's *Natural History* was very extensive, not only in his own time, but throughout the Middle Ages. There was something about the easy writing of uncritical comments on animals and anecdotes that was agreeable to mediæval readers. It was one of the most widely read treatises of mediæval times.

PLINY AND MAGIC

This is a convenient place to indicate in a general way the relation between science and magic which has been so thoroughly treated in the recently (1923) published *History of Magic* by Lynn Thorndike. As Thorndike says, in another treatise, "Magic was not the outright invention of imagination; it was primitive man's philosophy, it was his attitude towards nature . . . it was a body of ideas held by men universally and which, during their savage state at least, they were forever trying to put into practice." The statement that magic was primitive man's attitude towards nature is very significant, because science is the study and interpretation of the phenomena of nature. Accordingly, we can see that necessarily all science would be most intimately connected with magic which represented primitive man's attitude towards nature. Belief in magic antedated the rise of science, it was not only the foster-mother of science, it was the very root and branch from which it sprang. "If we wish to sum up the whole history of magic in a sentence, we may say that men first regarded magic as natural, then as marvelous, then as impossible and absurd. Today, in the thought of educated and sensible people, it is limited in actual significance to stage illusions; once it was a universal attitude towards the universe. As one false hypothesis after another was superseded by true notions, the content of magic narrowed in men's minds until at last it became an acknowledged deception. Meanwhile, its mistaken premises and strange proceedings first mingled with and then vanished into science and scientific methods." [1]

[1] Thorndike's *The Place of Magic in the Intellectual History of Europe*, p. 34.

Pliny's encyclopædia, or so-called *Natural History*, represents the connection between science and magic. In his time, in the western world the belief in magic was wide spread among highly educated and thoughtful people. Although Pliny pretends to be free from it, his book is nevertheless a reflection of the attitude of his time towards nature, and he is actually one of the best representatives of the belief in magic. Thorndike's comments on this point are too lucid to attempt to paraphrase: "Pliny, as we have seen, made a bold pretense of utter disbelief in magic, and also censured the art on grounds of decency, morality and humanity. Yet despite this wholesale condemnation, in some places in his work it is difficult to tell where his quotations from magicians cease and where statements which he accepts recommence. Sometimes he explicitly quoted theories or facts from the writings of the 'magi' without censure and without any expression of disbelief. It is contended that he none the less regarded them as false and worthless, we may fairly ask, why then did he give them such a prominent place in his encyclopædia? Surely we must conclude that he really had a liking for them himself and more than half believed them, or that previous works on nature were so full of such material and his own age so interested in such data that he could not but include much of this lore. Finally, many things which Pliny states without any reference to the magi seem as false and absurd as the far-fetched assertions which he attributes to them and for which he shows so much scorn. Indeed, it hardly seems paradoxical to say that he hated the magi but liked their doctrines.

"What clearer example of magic could one ask than the conclusion that the odor of the burning horn of a stag has the power of dispelling serpents, because enmity exists between stags and snakes, and the former track the latter to their holes and extract the snakes thence, despite all resistance, by the power of their breath? . . . Or that since the stag is not subject to fever, the eating of its flesh will prevent that disease, especially if the animal has died of a single wound? What more magical than to fancy that the longest tooth of a fish could have any

efficacy in the cure of fever? Or that excluding the person that has tied it on from the sight of the patient for five days would complete a perfect charm? Or that wearing as an amulet the carcass of a frog, minus the claws and wrapped in a piece of russet-colored cloth, would be of any aid against disease? Yet the *Natural History* is full of such things." [2]

It is important that the student of the history of science should take into account this aspect of the intellectual development of mankind. Magic came before science — as the attitude of primitive man towards nature; it was the root from which primitive religion and science sprang. Then all three mingled together in the early stages of science and religion, and only gradually did these latter emerge from the early beliefs that grew up around the contact of primitive man with nature.

DIOSCORIDES

In the first century of the Christian era there appeared in Greek a *Materia medica* of Dioscorides which, from the standpoint of extensive use, must be recognized as one of the most influential botanical compositions ever written. The wide and long-continued attention given to this composition was not owing to its superlative qualities as a botanical treatise but to its practical aspects. Between Theophrastus and Dioscorides, a period of four centuries, there had arisen a few minor writers on botany, and, at least, one important plant illustrator. This was Crateuas, mentioned with two other plant illustrators by Pliny in his *Natural History,* but whose original works have been lost. The figures, produced in natural colors by this early illustrator, are now regarded as the source of at least a part of the beautiful plant pictures found in some of the manuscripts of Dioscorides of the fifth century and later, as well as in certain other botanical manuscripts (Max Wellmann, 1898; Charles Singer, 1921). This entitles a hitherto little known name to a place in the

[2] *The Place of Magic in the Intellectual History of Europe*, p. 44. For a more detailed account see Thorndike's *History of Magic and Experimental Science* (1923), chapter II.

history of botany as one of the important early contributors to effective illustration of plants drawn from nature. Crateuas was a writer on plants as well as an illustrator, and some fragments of his writings have been detected in the famous manuscript of Dioscorides prepared in Constantinople for Julia, the daughter of the Roman Emperor, Flavius Anicius, about 512 A.D.

Pedanios Dioscorides (circa 40–90 A.D.) was a Greek physician who, as a medical officer with the Roman legions, had traveled in Italy, Gaul, Spain, Germany, Greece, etc., and had made observations on plants, animals, and minerals from the standpoint of their uses in medicine. Biographical facts regarding him are scanty; it is known that he was a Cilician Greek, born in Anazarbas, but no reliable information exists as to the date of his birth and death nor as to where he received his training — though it is conjectured that he had his medical training at Alexandria. The little known of his life is found in the preface to his *Materia medica,* which gives meager glimpses of his tastes, his travels, his times, and of his observations and care in accumulating facts. The treatise is dedicated to his friend, Areios, an Asclepiad of whom he speaks as the friend and protégé of Læcanius Bassus. According to Tacitus, this Læcanius Bassus was Roman Consul, in the year 64 A.D.; furthermore, Dioscorides served as a military surgeon under Nero (54–68) and thus we are able to place him in the middle of the first century A.D., as a contemporary of Pliny. The portrait of Dioscorides, Fig. 8, comes from the Julia Anicia manuscript and is probably an authentic likeness. Portraits of the period are common; they were done both in sculpture and painting; in fact, "The hack portrait painter at the street corner who did your portrait quickly for you was about as common as our own portrait photographer." (Breasted.)

DIOSCORIDES' MATERIA MEDICA

Dioscorides makes great claims to being more careful and accurate than his predecessors, saying that they have made many mistakes, and often have taken matter on hearsay, while "I

have seen and well considered most of the things of which I shall speak." Excerpts from his preface follow: "Having from my youth had a conscious and incessant desire to learn about materia medica, and after wandering through many lands, . . .

FIG. 8. — DIOSCORIDES, 130–201 A.D. RESTORED FROM THE JULIANA ANECIA MS., FOL. 4, VERSO, ABOUT 512 A.D. (*Studies in the History and Method of Science.* Reproduced by permission.)

at thy instigation (dearest Areios) I have reduced this into five books which I dedicate to thee, desiring to commemorate a reciprocal friendship . . . as thou hast always shown me an especial friendship above others. . . . For the rest, I wish to implore thee and all others who shall read my commentaries not to judge of my sufficiency by my style,[3] but rather by the diligence I have employed in investigating the matter and the experiences I have had with them. For I have seen and well con-

[3] Galen says that Dioscorides used poor Greek and did not understand the meaning of some Greek words which he employs defectively. In a letter Professor Thorndike says: "This would indicate he was not Greek but Asiatic."

sidered most of the things of which I shall speak; the others I have touched upon according to the report of authors who speak of them without controversy, and of still others (plants), I have diligently informed myself from those who inhabit the regions where they grow — in order to know the entire truth. Touching my manner of proceeding, it will be entirely different from others, for I seek to arrange the species of each simply (not merely alphabetically but) according to their virtues and properties."

His claims to personal observations and diligent inquiry regarding plants are in the main supported by reading his text. Although he makes extensive use of his predecessors, he is not a mere slavish compiler, but rearranges the matter and adds a personal touch to the composition. Nevertheless, one comes from the reading of Dioscorides with the impression that he has been greatly overrated as a writer. He was not scientific, like Theophrastus, nor a comprehensive genius, like Galen. He touches only a special side of plants — their medical uses. He seems not to have known the work of Theophrastus, who is incidentally mentioned only in two places — and these references are probably interpolations or derived from another writer. Among others, he mentions especially Crateuas and Andreas upon whose writings he seems to have drawn extensively. (See below regarding similarities between Dioscorides and Pliny.)

His writing is terse, without grace of style or rhetoric, and is very uneven as to description and treatment of the different topics. Each plant, animal, or other product of nature forms the subject of a chapter. The more complete chapters are very good, embracing terse comments on habitat and distribution, on root, stem, leaf, flower, fruit, and seed, together with medical effects, means of distinguishing the best kinds, procedure of preparation, dosage, etc. However, in many instances, all marks of identification are lacking and the whole chapter is made up of a few lines regarding medical qualities. His chapters on plants are the best; those on animals (about sixty-five to seventy) are short comments of seven to fifteen lines on their uses in medicine,

without description or means of identification. Thus we see that the *Materia medica* of Dioscorides, although treating of plants, animals, and minerals, was written in no sense to serve as a natural history, but only as a sort of pharmacopœia or medical botany. Being intended primarily to acquaint the reader with the medical properties of plants, and how to recognize the plants and their products, the work of Dioscorides was very different in design from the writings of Theophrastus on botany. Theophrastus was the greatest of all Greek botanists, and his *Historia plantarum* and *De causis plantarum* were conceived and written in a truly scientific spirit. As to quality, the work of Theophrastus stands high above that of Dioscorides, but the work of the man of applied science had the stronger practical appeal and received much attention, while the more truly scientific work of Theophrastus was neglected.

The great importance of Dioscorides lies in the general influence of his writings in keeping botanical matters before the public mind. His work was held in high esteem and enjoyed immense popularity for many centuries after his death; he even came to be thought of as the greatest botanist of all time — a popular verdict which was misleading, to say the least. The flair for him had already begun in the time of Galen (131–201) who praised him highly while criticizing him in detail.

DIOSCORIDEAN MANUSCRIPTS

An illustrated Latin translation of the *Materia medica* was current in the time of Cassiodorus (490–585) who recommended it to his cloister brothers who were unable to read Greek. The surviving Latin manuscripts, however, date from the ninth century.

There is no uniformity in the large number of Dioscoridean manuscripts that have survived. They were copied and recopied in the different monasteries and the transcribers made alterations and added extraneous matter from other manuscripts so that after the fourth century the manuscripts current under the name of Dioscorides were in fact composites and by no means

represented the work as it had been left by the author himself.[4]

The question of the manuscripts of Dioscorides is a matter of such detail that it cannot be entered upon here. Singer (1921) gives the facts regarding nineteen Greek manuscripts. One of the earliest and most famous of these (about 512) is the beautifully illustrated *Codex Juliæ Aniciæ*, above referred to, and formerly known as the *Vienna Codex*. This is a veritable *édition de luxe* of the period, prepared at Constantinople, evidently at great expense, as a wedding gift to Julia, the daughter of Flavius Anicius Olybrius, Emperor of the West. Formerly, as its earlier name implies, it was kept at Vienna in the Hofbibliothek, but is now in the St. Marks Library at Venice. From its place of production, it also goes under the title of the *Constantinopolitanus*. It has been photographically reproduced, and published with comments, an extensive preface and a Latin translation, in two sumptuous volumes of ponderous size and weight. This facsimile edition was published at Leipzig, in 1906. The illustrations are in some cases very fine. Some of the pictures are full-page and others are smaller, surrounded by the Greek text.[5] Those occupying a full page are generally about ten by twelve inches in size, showing root, stem, leaves, and flower, carefully executed from nature. It is probable that some of the pictures were copied from the pictures of Crateuas, but whatever their source, whether from earlier designers or executed at the time, they bear internal evidence of having been drawn originally from nature. In this codex the art of pictorial illustration is carried to a high degree of excellence.

[4] Charles Singer has shown with great clearness in a graphic table the geneology of the oldest manuscript of Dioscorides. For further details and much new matter the reader is referred to Singer's article in "Studies in the History and Method of Science," Vol. 2, 1921.

[5] In the four hundred ninety-one folio pages of the Greek text — each sheet measuring three hundred eighty by five hundred thirty mm. — there are four hundred eighty-four illustrations — three hundred eighty-eight of plants and ninety-six of animals; there may have been even more than this as several folios are lacking or blank. In Mrs. Arber's book on Herbals, there are reproduced, in reduced size, three of the plant pictures from this manuscript which convey a fairly good impression of the appearance of the illustrations.

It is interesting to note that this manuscript was prepared after the overthrow of Rome (476), particularly as it enables us to contrast world-conditions in the East and the West at that time. Society was so upset in the West that work of the quality of this codex could scarcely have been produced at Rome. In the East, however, conditions were more stable; the

FIG. 9. — SEEDLING BEAN: JULIANA ANECIA MS.
(From the same book.)

Greeks there were still able to indulge their feeling for fine workmanship.

An illustrated codex of the tenth century from the collection of the late Sir Thomas Phillipps of Cheltenham, England, has recently come into possession of the Pierpont Morgan Library, New York City. As to preservation and extent, this is probably the most complete and finest of the surviving manuscripts of Dioscorides.[6] Two other manuscripts are of high importance — the

[6] This codex is said by Charles Singer (letter to Dr. Fielding H. Garrison) to be superior to the *Julia Anicia* and to contain finer and more numerous illus-

illustrated Paris codex of the ninth century, and the *Neapolitanus*, prepared in the seventh century, formerly at Vienna, now at Venice.

Dioscorides and Pliny were contemporaries, and so far as can be determined, the *Materia medica* and the *Natural History* were produced almost simultaneously (about 77 A.D.). Neither author mentions the other, and the inference is that neither consulted the writings of the other. There is no reason to suspect that they borrowed directly from each other without giving credit, but evidently they used similar sources. The resemblance between them is so close verbally that the parallelism seems to indicate that Crateuas, whose writings are lost, was a primary source for Dioscorides as he was for Sestus Niger, and that Pliny compiled from Niger. The question is somewhat involved; possibly Dioscorides also used the writings of Niger, but he certainly made use of those of Crateuas, and, as stated above, some fragments of Crateuas have been identified in the Julia Anicia manuscript.

PRINTED EDITIONS

After the introduction of printing, the Greek text and Latin translations were published. "From the year 1516, when the first excellent translation by Ruellius appeared, Latin versions became numerous; and for a whole century thereafter the most voluminous and most useful books of botany were in the form of commentaries on Dioscorides. Such in large part are the works of Anguillara, Matthiolus, Maranta, Dodonæus, Cesalpinus, Fabius Columna, and the Bauhins. In several of these, the annotations and comments quite exceed in bulk the Dioscoridean text and are replete with new botany. . . . One may fairly say that the greater part of all the new botanical matter published during the whole of the sixteenth century, and part of the seventeenth, came out in the form of annotations upon

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trations — in some cases resembling closely the illustrations of the *Constantinopolitanus* but "not copies."

the text of Dioscorides. Thus it appears that the Greek, who meant only to provide medical students with a full compend of remedies, and of the marks by which to know them, became incidentally the first master of phytography, the one every line of whose plant descriptions has been more attentively studied word by word, and that by a greater number of erudite men than any other book about plants that has ever been written; unless one should possibly be obliged to make an exception of Bauhin's *Pinax*." (1623). (Greene.)

Printed editions of Dioscorides' work exist in considerable number in several modern languages, and there is no lack of opportunity for those who wish to examine the Dioscoridean text. The German translation of Berendes from the Greek, 1902, is excellent for reference.

GALEN

In Galen we have an investigator of truly scientific spirit living in a age of scientific decline. He is separated from the rest of the naturalists of his epoch by his methods, by the qualities of his mind, and by his product. With few exceptions, such as Ptolemy in astronomy and geography, the men of his time who were inclined towards natural science were mere compilers from the works of others — and, more than that, content to be compilers. Dioscorides showed some originality in describing plants, but Galen exhibited originality in an eminent degree and in a broader field of investigation. He was not only observer, but also experimenter. It is to be noted that Dioscorides and Galen were Greeks though living in Rome and having their intellectual product classified as within the Roman period. They were different from the Romans in heredity and had inherited the Greek cast of mind. They were original and inclined towards scientific methods, while their famous confrère, Pliny, the writer of the natural history, was a Roman and exhibited the very different qualities of mind which have already been spoken of as distinctly Roman.

An examination of Galen's writings is almost certain to leave

one with the conviction that he was one of the great anatomists and physiologists of all time. He was exalted to such eminence as an authority during the Middle Ages that when the reaction came, with the reform of anatomy and physiology by Vesalius and Harvey, it became the fashion to undervalue his work in anatomy and physiology, and the spirit of this reaction has continued even to this day. It is not generally understood that both Vesalius and Harvey held Galen's attainments in high admiration though they were obliged to point out some of his more striking errors and to oppose his authority. Their advances were made by rigorous adherence to the methods employed by Galen. It was not Galen's fault that his remote followers proclaimed him an unfailing authority. Such procedure was in fact contrary to his own principles; in cases of controversy as to structure or function, his method was always to appeal to dissection and experiment. He believed so little in authority that he excluded from his *Anatomical Administrations* some observations on anatomy attributed to Herophilus and Erasistratus because he was unwilling to include what he had not seen himself. Had not Galen published his observations on anatomy and physiology, it is unlikely that Vesalius and Harvey would have accomplished what they did. Galen was in a way their indispensable forerunner.

Galen[7] (Fig. 10) was born in 131 A.D., at Pergamos, which for some centuries had been an important city of Asia Minor — a city of Greek culture, which at an earlier day had competed with Alexandria in collecting manuscripts for its large library. Under the rule of enlightened despots, science and learning had long been cultivated in Pergamos, and Galen's father, Nicon, who was a prosperous architect, gave personal attention to the education of his son, according to the methods of the time, and later provided him with the best of tutors. After the boy had reached the age of twenty, the death of his father left him to fashion his own life. He then went to Alexandria to complete

[7] "From the fifteenth century on, the erroneous form 'Claudius Galen' has been employed. Klebs (Proscopgraphia imperii Romani, 1897, I, 374–380) shows it to be a misreading of Cl(arissimus) Galen." (Sudhoff-Garrison.)

FIG. 10. — GALEN, 131–200 A.D. (Acta medicorum Berolinensium, Vol. 5, 1719.)

his medical education — already begun in Pergamos — and for several years traveled extensively, absorbing in various cities the best of the thought and instruction of the day. On his return to his native city, he was appointed medical attendant of the gladiators — a position usually reserved for medical men of experience as well as of high standing. After four years he went to Rome for greater opportunities. There, through natural talent as well as by successful medical treatment of high officials and aristocrats, he became famous. He instituted public lectures and demonstrations in anatomy and physiology, which attracted attention of prominent and influential people and increased his fame. Professional jealousies were aroused by the growing popularity of the newly-arrived practitioner, and the other Roman physicians became so hostile in their attitude towards him that he returned to Pergamos. Confidence in his skill remained, however, in high quarters, and not long after, he was summoned by the Emperors Marcus Aurelius and Lucius Verus to the battlefields of the Romans and the Germans. For some reason his service as a military surgeon was short, and he went to Rome, becoming the personal physician of Marcus Aurelius and his sons, Commodus and Sextus. In this new office he had what he greatly desired — time for writing and opportunity for conducting work in anatomy and experimental physiology. He was industrious and a large amount of original work was the result. Galen was a prolific writer. This is attested by some two hundred titles of works ascribed to him. But we shall here neglect his writings on the practice of medicine, on philosophy, metaphysics, and like topics, and give a summary account only of his writings on anatomy and physiology which have influenced the progress of natural science.

His Work in Anatomy. Galen was easily the leading anatomist of his day and retained his primacy up to the time of Leonardo Da Vinci (1510) and Vesalius (1543). (Though in the interval, Mondino (1315) and Carpi (1421) practised dissection of the human body, their contributions were less extensive and exact than Galen's.) Between Erasistratus (about 300

B.C.) and Galen (second century A.D.) the practice of dissection of the human body had been proscribed by law, and the circumstances under which Galen worked were less favorable than those attending Herophilus and Erasistratus. As we have seen, in the earlier Alexandrian times dissection of the human body was permitted, was in fact favored, by the enlightened Ptolemy Philadelphus and others. But Galen was an enthusiast in anatomy and made the best use of his limited opportunities to become acquainted with mammalian anatomy. He was a comparative anatomist, and dissected fishes, turtles, swine, (once an elephant), as well as many Barbary apes.

He had for reference the anatomical writings of Herophilus and Erasistratus, but no opportunity to investigate the structure of the human body by actual dissection. He had seen two human skeletons in Egypt and accounted this a great help, but for the structure of the soft parts — the muscles, the viscera, the circulatory system, etc. — he was thrown back to the investigation of brute creation. It is not necessary to go into detail regarding his knowledge of the structure of vertebrated animals. It is sufficient to say that his work on the muscles was especially defective, but that he made some very good observations on the bones, the brain, and spinal cord, the peritoneum, the heart, etc. He prepared a work on dissection, the *Administrationes anatomicæ*, which was a standard reference for centuries to come.

It is in his work on the brain, the spinal cord, and the nerves, that we find him at his best. By dissection of the brain of the ox, he made out clearly the main features to be detected by the unaided eye. The same thing had, indeed, been done by Herophilus and Erasistratus, but the account of Galen has the freshness and vigor of a genius personally acquainted with these structures. He perceived that the nerves are connected with the brain and the spinal cord, and that the spinal cord is a continuation of the nervous substance of the brain. He saw also that muscles contract in response to some stimulus coming to them through the nerves, and that, if a part be separated from its nerve, or if the continuity between nerve and central nervous system be broken,

then the part concerned loses power of motion and sensation. He studied both the nerves of the brain — of which he knew seven pairs — and of the spinal cord, and separated the nerves into those of motion and sensation.

"The muscles," he says, "move certain organs, but they themselves require, in order to be moved, certain nerves from the brain, and, if you intercept one of these with a ligature, immediately the muscle in which the nerve is inserted and the organ moved are rendered motionless."

"I will prepare several animals, and show that sometimes one, sometimes another, of these activities is abolished when the several nerves are divided." Galen wrote a special book on dissection of the nerves in order to demonstrate the connection with the brain. He says, "It is admitted by all *physicians* that no part of the body has what we call voluntary movement or sensation without a nerve, so that, if the nerve be cut, the part immediately becomes motionless and insensate. But that the brain is the origin of the nerves and likewise of the spinal marrow, and that the nerves arise, some from the brain, some from the spinal marrow, is not known to all." "His conceptions of the nerves in relation to sensation and voluntary motion were essentially the modern ideas. Galen's experimental investigation of the spinal cord by sections at different levels and by half-sections was still more remarkable. It is quite modern in precision and completeness." (Payne.)

Galen was able to make practical application of such knowledge. He was not merely a patient and plodding observer who pointed out facts of structure — his mental powers were constructive and he was able to reason from observations to their significance. This quality, which shows Galen's grasp of experimental results, is illustrated by the following anecdote. One of the Roman aristocrats had a numbness in the third and fourth fingers of his left hand and was being treated by Roman physicians by local application of poultices — and without beneficial results. Galen, suspecting that the trouble was connected with the nerve supply, took a careful history of the case and found

that some time previously the patient had been thrown from his chariot and had fallen on his back. Accordingly, he began to treat the source of nerve supply at a long distance from the local disturbance, which resulted in a cure and an increase of his reputation.

Experimental Physiology. The extent of Galen's physiological experiments has not been sufficiently recognized. With all his errors of interpretation which have been repeatedly pointed out by modern writers — there remains a substantial residuum of experimental observation. His mistaken inferences were largely owing to the state of knowledge in his time and not to his methods nor to his insight. As we have said before, the question is often raised: "Did the ancients engage in experiment?" It is of importance that we should consult the writings of Galen on experimental physiology because the question is usually answered in the negative.

Galen's experiments with the nervous system have been well commented on by Charles Daremberg, who translated his anatomical and physiological writings into French, repeating most of his physiological experiments, and by Neuberger, the eminent historian of medicine. Besides Galen's well-known experiments on the nervous system, there are some others, related in detail in his treatise *The Natural Faculties,* that are infrequently referred to. His experiments on the function of the ducts leading from the kidneys to the bladder (ureters) involving the use of ligatures, show that he was an operative experimenter whose experiments were well thought out before they were begun, and who used the most direct method for answering the question involved. In this particular he showed a certain resemblance to Claude Bernard, the greatest experimental physiologist of the nineteenth century. It is perhaps not an exaggeration to say that Galen was the founder of experimental physiology, though his foundation was not utilized until the advent of Harvey, some fifteen centuries later.

For full details of the experiment on the ureters, one must refer to page 59 of the English translation of Galen on the

Natural Faculties, by John Brock,[8] of which some excerpts will follow. In a controversy with Asclepiades, one of the Sophists, regarding the use of the ureters, Galen, as usual, answered with an experiment. The Sophist declared that in the case of any bladder "if one fills it with water or air, and then ties up its neck and squeezes it all round, it does not let anything out at any point." "And surely," said he, "if there were any large and perceptible channels coming into it from the kidneys, the liquid would soon run out through these when the bladder was squeezed in the same way that it entered." As an anatomist, Galen knew the exit of fluid through the ureters would be prevented from the fact that the ureters run for nearly one inch obliquely through the wall of the bladder before opening into its cavity. His experimental demonstration is related in these words: — "Now the method of demonstration is as follows. One has to divide the peritoneum in front of the ureters, then secure with ligatures, and, next, having bandaged the animal, let him go. . . . After this, one loosens the external bandages and shows the bladder empty and the ureters quite full and distended. . . . On removing the ligature from them, one then plainly sees the bladder become filled with urine.

"When this has been made quite clear, . . . one has to tie a ligature round the orifice and then squeeze the bladder all over; still nothing goes back through the ureters to the kidneys. . . . These observations having been made, one now loosens the ligature from the orifice allowing the bladder to be emptied, then again ligatures one of the ureters and leaves the the other to discharge into the bladder. Allowing, then, some time to elapse, one now demonstrates that the ureter which was ligatured is obviously full and distended on the side next to the kidneys, while the other one — that from which the ligature has been taken — is itself flaccid, but has filled the bladder. Then, again, one must divide the full ureter, and demonstrate how the urine spurts out of it, like blood in the operation of venesection; and after this, one cuts through the other also. . . . Then, when

[8] Loeb Classical Library, 1916.

enough time seems to have elapsed, one removes the bandages; the bladder will now be found empty, and the whole region between the intestines and the peritoneum full of urine, as if the animal were suffering from dropsy. Now, if anyone will but test this for himself on an animal, I think he will strongly condemn the rashness of Asclepiades, and, if he also learns the reason why nothing regurgitates from the bladder into the ureters, I think he will be persuaded by this also of the forethought and art shown by Nature in relation to animals."

Galen's experiments on the muscles and nerves of the œsophagus [9] are also clear, exact, and complete. These experiments together with those on sections of the spinal cord at different levels show a wide range of experiment with well thought out design. His experiments were not a few sporadic attempts undertaken out of curiosity; they are sufficient to entitle him to notice as one of the great pioneer experimenters in physiology. His writings contain a larger number of physiological experiments than all those ascribed to Harvey.

The overwhelming mass of Galen's complete writings [10] need be no barrier to getting some first-hand acquaintance with him as a writer. In the recent English translation of his *Natural Faculties*, comprising only one hundred sixty-five duodecimo pages, one can find an epitome of his style and methods of reasoning and experimentation. The translator, Dr. Arthur John Brock, says: "If Galen be looked on as a crystallisation of Greek medicine, then this book may be looked on as a crystallisation of Galen. Within its comparatively short compass we meet with instances illustrating perhaps most of the sides of this many-sided writer. The *Natural Faculties*, therefore, forms an excellent prelude to the study of his larger and more specialized works. Galen was a master of language, using a highly polished variety of Attic prose with a precision which can be only imperfectly reproduced in another tongue." Galen's allusion to the barbarous Greek of Dioscorides (who came from the provinces and probably used a dialect) has been mentioned above.

[9] The same book, p. 273. [10] Twenty octavo volumes in Kühn's edition.

Galen was the last representative of the Alexandrian school of Hellenic science. After him no great investigator of natural science arose in western Europe until Vesalius appeared in 1543, though as possible exceptions to this general statement we might mention Bock and Valerius Cordus in their observation of plants.

His Influence. The influence of Galen was projected far beyond his time. During the Middle Ages he was proclaimed both in the East and in the West as the greatest authority in all branches of medicine. In order to understand what this meant in the mental life of the Middle Ages, we need to remember that authority came to be accepted as the source and criterion of knowledge. The direction of education had fallen into the hands of the theologians, and, as the Scriptures were accepted as the infallible guide to spiritual life, it was natural that the theological method of exposition should be adopted as their educational method. After the fall of Rome in 476, Galen's writings were recognized as authority in medicine and in anatomy. In anatomy, where observation is the only secure basis for instruction as well as for progress, the subject was taught by reading and expounding Galen from the teacher's desk.

Scientific heritage was not to be further improved until after the Renaissance. If we take a retrospective glance over the half-millennium from Aristotle to Galen, we recognize these two as men of unusual caliber. Their genius, their mentality, and the positive results of their observation, place them in the first rank. Theophrastus, Erasistratus, Herophilus, and Dioscorides are men of smaller stature, while Pliny must be rated only as a populariser and not as an original student.

CHAPTER V

FROM GALEN TO THE THIRTEENTH CENTURY

It is now our concern to trace in outline the period between Galen and the notable outburst of creative impulses in the thirteenth century. During this long period of nearly eleven centuries, natural science made no real progress in western Europe. Galen's work marks the close of the ancient period, and after him no investigator of distinction arose until the time of Albertus Magnus and Roger Bacon. We pass over individual manifestations of independent thinking by such men as Alexander of Tralles (525-605), "the first doctor for a long time who had done any original thinking," [1] and several others. Natural science did not really become extinct but went into a state of decline and reached a lower level than it ever had in Hellenic times. For the time being the fine results of ancient Greek science were neglected. It is scarcely defensible to say that "In science there was no great product in antiquity to be lost." [2] For Aristotle, Theophrastus, Herophilus, Erasistratus, Galen, compare favorably with the foremost men of any century; they were men of true scientific spirit and their results from positive observation and experiment are worthy of recognition in the same spirit as the art, architecture, and literary productions of the ancients.

In any period the development of science is conditioned on the general culture and state of civilization. Natural science, in particular, is dominated by the prevailing mental attitude towards nature. We cannot construct the history of science without taking into account the state of education and the main currents of thinking, as well as the social and political conditions of the time. We must, therefore, study the *milieu* in which

[1] Puschmann, — Thorndike.

[2] Article Middle Ages, Ency. Brit., Eleventh edition.

science was placed during the Middle Ages in order to discover what were the conditions which held it in check for so many centuries.

During a part of the long period under consideration, successive invasions of the barbarians kept society in a state of turmoil and interfered with constructive progress. Later, however, conditions were more favorable, and with the help of the Church, that great civilizing and conserving factor, affairs of the mind were more active. It is a misconception to suppose that the fabric of natural science was completely destroyed at this time. Antiquity had laid lasting foundations, and although the early Middle Ages covered these as with the debris and ashes of a volcanic eruption, they were uncovered in the later Middle Ages, and modern science was built on these foundations.

But the pause in scientific inquiry, in particular, was not owing so much to general conditions of illiteracy and lack of mental pursuits, as to the fact that men were thinking about other problems. Besides the disturbed social and political conditions of the Middle Ages, there were causes of an intellectual nature that delayed progress. The great struggle between pagan and Christian ideals absorbed the thinking of the best minds of the time. Education was in the hands of the religious orders, and in form and spirit was mainly ecclesiastical. In the palace schools as in the cathedral schools, the teachers were clerics. The world came to be looked on, by thinking men, as a temporal world of sin, to be shunned in all its aspects. There grew up a distinct hostility to Greek science as a product of pagan civilization. The Greeks, and other ancient people, had shown a sympathetic attitude towards nature; for them the *Cosmos* signified the universe in its well ordered unity — friendly to man and closely related to his spirit. With the early Christian writers this was all changed, and the significance of the word, *Cosmos,* became restricted to the terrestrial world of sin in opposition to the celestial world (Carus). The world-shunning spirit of the early Christians was sedulously cultivated for centuries and inevitably created an attitude hostile to the study of nature. Fur-

thermore, as we have already said, the theological method of reliance on authority spread into other fields of study and came into direct, and for a time triumphant, opposition with the investigating spirit of science. Thinking, removed from the contact with the external world, became subjective, and there began a long struggle between subjective and objective methods of study.

In the West, the teachings of Christianity changed the motive of man's thinking. The master-motive became to save the soul, and the method proposed dispensed with natural phenomena. Indeed, the Christian position was that the Scriptures were all-sufficient for man's intellectual needs. Nothing shows this more clearly than the statement attributed to Tertullian: "Investigation, since the Gospel, is no longer necessary." In a like manner, the Moslems held that the teachings of the Koran made investigation superfluous. Nevertheless, secular thinking and writing were going on, though subject always to the dominant preference for the subjective method, metaphysical speculation, philosophical doctrine, and reverence for authority.

The period of the Middle Ages in western Europe, extending roughly from the overthrow of ancient civilization to the Renaissance, is one of the least understood periods of history. The decline was not abrupt but gradual, beginning some centuries before Rome fell into the hands of the barbarians in 476. From the standpoint of the progress of natural science, the Middle Ages extend from the last productive work of Galen, about 200 A.D., to the revival of the scientific method by Vesalius in 1543. The sources of information bearing on this period have scarcely been assimilated by historical scholars; many of the most important are in manuscript, and they await systematic analysis. It may be noted in passing that some of the mediæval manuscripts relating to natural science, to medicine, and to magic in its relation to science and experiment, have been dealt with by Karl Sudhoff, of Leipzig, Charles Singer, of London, and Lynn Thorndike, of Cleveland — as well as by others. We can do little more here than take a fleeting glimpse of the condition of

education, book multiplication, book reading, and of the few treatises available at the time touching on natural history.

One of the best known circumstances affecting the preservation of scientific knowledge in the Middle Ages is the service rendered by the Saracens in duplicating manuscripts of Greek scientific works and transmitting them to western Europe in the twelfth century. This fact has been so repeatedly emphasized that one is likely to overlook, or at least to underestimate the part played in the West by the Christian religious orders in conserving and duplicating the manuscripts of classical antiquity. The Christian church was the best organized agency and the greatest single civilizing factor of the time. The monasteries of western Europe were repositories of classical manuscripts and many of these were duplicated in the scriptoria, or writing rooms, and were put in circulation. It is true that the western monks neglected the writings of Aristotle on natural history, but they copied many other manuscripts and aided immensely in the spread of literature and in education.

Although the dominant currents of thought were religious and philosophical, some writings of scientific nature were still read in the west. Cassiodorus (490–584) mentions specifically an illustrated codex of Dioscorides in Latin translation and recommends it to those not able to read Greek. Various works with scientific titles also existed in which the contents did not bear out the title.

THE PHYSIOLOGUS

This was a kind of Natural History widely circulated in the Middle Ages; it must have been well known to the masses, who heard quotations from it by the popular preachers. It is of uncertain origin, but was probably an Alexandrian production of the period of decline, dating from the third or fourth century A.D., and was indeed a natural history of a very low grade. In its earliest form it mentioned trees and stones as well as animals. In the course of a number of changes it came to be restricted to animals and is known also as the *Bestiarius*. It appears that

the original purpose of the *Physiologus* was to give an account of natural phenomena without any attempt at moralization. Later, it was adapted to theological uses, since reference to animals was popular in the pulpit. Manuscripts of the *Physiologus* exist in various forms, both prose and poetical, in ten or twelve languages of eastern and western Europe. In the more widely distributed issues, the book contains accounts of the animals mentioned in the Bible and of others of a purely mythical character. These animals symbolize religious beliefs, and the discussion of them is often accompanied by quotations of texts and by moral reflections. The phœnix rising from its ashes typifies the resurrection of Christ. Regarding young lions, the *Physiologus* says: " The lioness giveth birth to cubs which remain three days without life. Then cometh the lion, breatheth upon them, and bringeth them to life. . . . Thus it is that Jesus Christ during three days was deprived of life, but God the Father raised Him gloriously."[3] Besides forty or fifty common animals, the unicorn and the dragon of the Scriptures and the fabled basilisk and phœnix of secular writings are described, and morals are drawn from the stories about them.

Carus in his history of zoölogy ascribes a great influence to the *Physiologus,* pointing out that during the early Middle Ages all writings of pagan sources were condemned by Christianity. " It was, therefore, of the greatest importance for natural history as an agent of civilization in general to find a form of exposition which under the approval of ecclesiastical authority preserved the taste for nature. This the *Physiologus* offered. Its importance is found in its wide diffusion.

Carus gives a detailed analysis of the contents of the *Physiologus,* which, in itself, is of great service, but seems to be an over-estimate of its influence on natural history. Probably, it kept alive some thoughts regarding natural objects, but its science was of such low grade and it touched on animals in such a casual way that it could have but little influence on the progress

[3] A. D. White, *A History of the Warfare of Science with Theology in Christendom,* p. 35.

of natural history in a time when Pliny's *Natural History* and Galen's treatises were also reproduced and read.

Besides the *Physiologus,* the *Etymologies,* or *Origins,* of Isidore of Seville (ca. 623), which contained brief excerpts from earlier scientific writers to illustrate the derivation of words, was much read, although its scientific matter was meager indeed. As a matter of fact, the treatises of supreme writers on natural history, Aristotle and Theophrastus, were not current until after the eleventh and twelfth centuries, when translations into Latin from the Greek and retranslations from Arabic began to be made. Even then Theophrastus was neglected in favor of Dioscorides, though Aristotle began to exert an influence on natural history. His *Rhetoric* and *Logic* had been in use for some time, but the *Historia animalium,* though translated into Arabic and read in the East, was long left untranslated in the West.

MONASTERIES

Undoubtedly the monasteries of the West played a considerable part during the early centuries of the Middle Ages in preserving the thought of the ancient world, in duplicating manuscripts, and in keeping alive some intellectual pursuits. In the midst of turbulent social conditions, they were places of retreat, removed from the distractions of the world, and they attracted not only men devoted to the cause of religion but also men of studious habit. It might appear to a " practical mind " of today that these institutions would degenerate into places of idleness and useless routine without influence on the progress of civilization. On the contrary, they were centers of industry and initiative; their influence was constructive and they became agencies of progress.

Monastic life, led either by hermits or by anchorites sometimes living in groups, had existed in Egypt and the East for some centuries before 529; here we refer only to those associations of men in communal life known as monasteries. They became " the repositories of the learning that was, and the wellsprings of the learning that was to be." (Maitland-Putnam.) In

the year 529, Benedict of Nursia, founded the monastery of Monte Cassino, situated on a rocky eminence about midway between Rome and Naples. Here sprang up the society of the Benedictine monks. Benedict saw the necessity of industry; he announced that "Idleness is the enemy of the soul," and in the "Rule" of his community there was prescribed seven hours daily of manual labor and two hours of reading. This last item gave an impulse to study. The "manual" labor was liberally interpreted as including in some cases the copying of manuscripts in the scriptorium — an idea probably borrowed from Cassiodorus.

It is generally believed that Cassiodorus introduced the scriptorium into the monastery, causing sacred and secular literature to be copied, and himself superintending the translation into Latin of various ancient Greek writings. By inaugurating this activity, he became a sort of link between ancient and mediæval times, and acquired a lasting influence on centuries to come. Cassiodorus (circa 490–584) had been a man of influence in worldly affairs and had held important offices under the government of Theodoric and others. He was both scholar and statesman, and he saw the importance of preserving for future generations the choice literature of the world, now in danger of destruction by the invading hordes of barbarians. About 540, when he was nearly fifty years of age, he founded two monasteries on his ancestral estates at Vivarium and Castellum. Here he strictly enjoined the preserving and duplicating of manuscripts as one of the monastic duties. The practice was introduced into other monasteries and was inherited by those of later foundation. The copies of the manuscripts began to be circulated and the monasteries became the publishing agencies of the period.

MEDIÆVAL LIBRARIES

Incidental allusions to the libraries of monasteries, cathedrals, abbeys, and individuals, and references to collecting, exchange and sale of books, etc., lead one to believe that the scarcity of books in the Middle Ages has been much exagger-

ated. Putnam, in *Books of the Middle Ages,* gives a picture of book-production and book sale which is very informing. We learn that even in the first part of the Middle Ages, in the fifth century, Augustine had "many books"; that Isidore of Seville, in the seventh century, owned a large private collection; that the Abbey at York had a large collection in the eighth century; Gertrude, Abbess of Nivelle, ordered books from Rome in 658; Abbot Benedict sought books on different occasions during the seventh century not only in Rome, "but elsewhere." At Abbey Novalese there were sixty-five thousand volumes before its destruction in 905, and Gibbon speaks of the transport of a Doctor's library requiring four hundred camels.

Although this was a period of general illiteracy, there were educated people who read, in addition to the Scriptures, Ovid, Virgil, Seneca, Augustine's City of God, Pliny, Isidore, Aristotle's Rhetoric and Logic, and many other writings.

EDUCATION

To take part in education was one of the recognized monastic duties, and during the seventh and eighth centuries the Benedictine houses [4] were the chief agencies in christianizing and educating the barbarian invaders. From the beginning, boys were instructed at Monte Cassino with a view of preparing them for the life of brothers, and soon thereafter education was carried on outside the monastery by religious bodies. These outside schools were clustered around cathedrals and abbeys, and thus arose cathedral schools and convent schools. In the convents the instruction was largely ecclesiastical, but in the cathedral schools secular subjects were also taught. In the last half of the eighth century when Charlemagne undertook to introduce schools into his Empire, he brought an English monk, Alcuin (735–804) from York, to organize and supervise the system of education.

[4] We should not confuse the earlier religious houses with the influential orders that arose in the thirteenth century. Two of these later orders, the Dominicans and the Franciscans, took the lead in scholarship and learning and had prominent representatives in the universities. The motives of the earlier religious houses were essentially similar, but they belong to an earlier period of history.

Different views are held regarding Charlemagne's insight and intentions, but at all events, in the early part of the Middle Ages the times were not ripe for a general educational movement, and his revival of schools was temporary.

In the times of which we are speaking education was at a low ebb. Among the masses, thrown back on agriculture as a means of subsistence, a peasant attitude of mind prevailed. The monotonous round of life, the lack of education and of intellectual interests, led to stagnation and stolid indifference. There was no community of intellectual pursuits, and no general widespread intellectual hunger, until after the crusades and the founding of universities.

But though circumstances prevented the spread of education among the masses, the mental life of the upper classes, even in the first part of the Middle Ages, was by no means static. The welfare of the church and the establishment of Christianity on a firm basis, however, absorbed most of the thinkers. The direction of intellectual life went over into the hands of the religious bodies, and this gave to it an ecclesiastical character. Science suffered in estimation because it was the product of a pagan civilization, though some portions of it were adapted to the ideas of the church and used as a support to faith. It should be borne in mind, however, that the spirit of the times was against scientific investigation.

A GLIMMER OF SCIENTIFIC SPIRIT

As we approach the the twelfth century, we find from time to time the appearance of a different mental attitude. The broadening effect of the crusades, and the contact which they brought with the East, set new thoughts in circulation. For instance, Adelard of Bath (circa 1130), a contemporary of Abelard, shows an independent scientific spirit. In search of instruction, he traveled in Mohammedan as well as in Christian lands. On his return to England, his favorite nephew and other friends "urged him to disclose some of the new ideas he had learned among the Arabs." Agreeing to this he produced a pioneer book of the

natural sciences entitled *Very Difficult Natural Questions* (*Perdifficiles Quæstiones Naturales*), composed as a dialogue with his nephew. "Adelard upholds scientific argument and investigation against a narrow religious attitude. He insists that he is in no way detracting from God, whom he grants to be the source of all things, but that nature 'is not confused and without system,' and that 'human science should be given a hearing on those points which it has covered.' He also sets reason above authority; and sharply reprimands his nephew for following authority as if he were a brute led by a halter, for his bestial credulity, for his trusting simply in the mention of an old title. In fine, he tells his nephew that if their discussion is to go any further, he must drop authorities and 'give and take reason.' He assures his young relation that he is not the sort of man who can be fed on the picture of a beefsteak."[5] This as a single illustration marks a new attitude for the Middle Ages — a harbinger of the renewal of scientific methods of thought.

THE SARACENS COPY SCIENTIFIC MANUSCRIPTS

Having represented, in a very diagrammatic way, the conditions which affected natural science in western Christian Europe during the first part of the Middle Ages, we now turn attention to the Saracens, who played an important part in preserving Greek science for future generations. These people, "otherwise known as Arabs and Moors, belong to a great race of Semitic origin which had peopled Syria, the borders of the Red Sea, and the northern part of Africa." At their worst, they were terrifying marauders engaging in atrocious warfare in the name of religion, but, at their best, in the cities, they showed refinement of manners with a taste for splendor and, indeed, a high respect for learning. In the ninth century, while Charlemagne held sway in a disordered Empire of the West, and was trying to introduce the rudiments of education among his retarded subjects, Bagdad was famous for wealth, splendor, and education. At this time Bagdad, with an estimated popula-

[5] Thorndike, *Natural Science in the Middle Ages*, Pop. Sci. Mo., 1915.

tion of two million, was the seat of a university, and probably was the most magnificent city of the world. There were great scholars in the university of Bagdad, and these scholars, with the faculty of recognition which was engendered by their own mental pursuits, had a sympathetic feeling for other kinds of learning of which they were not the originators.

It is commonly stated that the "Arabians" were the conservers of science during the early Middle Ages, but it is to be understood that the designation, "Arabians," as employed in this connection is not restrictive but includes Syrians, Persians, Jews, and Christians who wrote on science under Arabic names. During the Middle Ages, up to the twelfth and thirteenth centuries, the Saracens were more to be considered, intellectually, than the Christians of western Europe. Arabian scholars made independent advances in mathematics, botany, chemistry, optics, and astronomy. They constructed magnificent buildings and introduced many conveniences of civilization, but with all their advances they were not temperamentally fitted to be pioneers and originators of natural science. They were poetical, imaginative, and inclined to subtilties of speculation; they had little talent for productive research and for verification of the results of observation. According to their religion, the dissection of the human body was a mortal sin, and this placed a stern limitation on morphological studies. In preserving natural science, the Saracens made only small contributions of their own; they acted chiefly as intermediaries between ancient Greek science, which they found ready-made, and the beginnings of modern science in the West.

In the actual transfer of Greek science to the Saracens, the sect of the Nestorians played a considerable part. This Christian sect, led by Nestorius, was driven from Alexandria as a result of religious disagreements. As the Nestorians went towards the east, they were hospitably received by the Mohammedans; they established schools in which Greek learning was the basis of instruction, and the Greek manuscripts which they carried with them were passed along to the Arabs. We have

seen that the natural science of the Greeks had been condemned by Christians as being of pagan origin, but the Mohammedans manifested no such prejudice against it. Their hospitable disposition towards learning led them to translate the Greek manuscripts into their own tongues and thus to preserve manuscripts that were in danger of extinction.

After the conquest of Spain by the Mohammedans in the eighth century, the Western division of the Empire advanced rapidly in civilization and learning. The caliphs both of the East and of the West were patrons of learning and science; they provided liberally for support of the universities. However remote may seem the unusual names of the caliphs and the Arabian writers, there is one figure made familiar alike to young and old in the stories of "The Arabian Nights" — Haroun-al Raschid (786–808), the celebrated Caliph of Bagdad during its period of highest development. He was a contemporary of Charlemagne and exchanged courtesies and gifts with him. Of the several universities founded by the Mohammedans in Spain that of Cordova became the most famous. Bagdad in the East and Cordova in the West divided the university influence between them. Aristotle was venerated as an authority by the Saracens, and not only were his scientific writings translated into Arabic, but they were extensively annotated by Arabian scholars.

Medicine is closely allied to natural science, and the Arab physicians drew from Hippocrates, from Aristotle, and, especially, from Galen and from Dioscorides. The nature of their studies led them to observe the human body, and in Aristotle and Galen they sought a better understanding of its activities. Some advances were made by the most gifted, especially in botany and pharmacy.[6] We have Arabian manuscripts of the

[6] During the Middle Ages there were several Arabian writers on animals, whose names, and the titles of whose works, have come down to us. Illustrations of these are: Dschahid (d. 868), whose book of animals, *Kitab-el-haiwan*, is said by Carus to be the fundamental work of Arabian zoölogy of the Middle Ages; the *Liber de animalibus* of Abou Asch'ath (d. 970); and the *Generatio animalium* of Abdul el Madschriti (d. 1007). But all these works are little known in detail and their contents have not been determined.

ninth century illustrated by sketches of the eyeball with its various coats, the crystalline lens, the optic nerve, etc., and, dating from the same period, manuscript sketches of the uterus. But we shall neglect here all the minor writers and speak only of two of the foremost, whose writings had considerable influence on the reawakening of natural science. These men were Avicenna and Averroës, both commentators of Aristotle.

AVICENNA AND AVERROËS

Avicenna (980–1037) was a restless, eager spirit, so precocious that at the age of ten, it is said, he knew by rote the entire Koran and much Arabian poetry besides. With his inquisitive intellect and retentive memory, he progressed rapidly and, having studied philosophy, metaphysics, logic, and other subjects including medicine, he engaged in medical practice at the age of sixteen. He began writing early and produced numerous treatises (about one hundred) some of which were short tracts and others extending through several volumes. His *Canon of Medicine* was for several centuries one of the most widely read books of medical science. Although he made no claim to a knowledge of natural history, he paraphrased Aristotle and produced a book on animals which was translated by Michael Scot.

FIG. 11. — AVICENNA, 980–1037. (Acta medicorum Berolinensium, Vol. 6, 1720.)

Avicenna's comments on the play of natural agencies in mountain-formation show that he had some tendencies towards the observation of natural phenomena. His views on moun-

tains and valleys are expressed as follows: " Mountains may be due to two different causes. Either they are the effects of upheavals of the crust of the earth, such as might occur during a violent earthquake, or they are the effects of water, which, cutting for itself a new route, has denuded the valleys, the strata being of different kinds, some soft, some hard. The winds and waters disintegrate the one, but leave the other intact. Most of the eminences of the earth have had this latter origin. It would require a long period of time for all such changes to be accomplished, during which the mountains themselves might be somewhat diminished in size. But that water has been the main cause of these effects is proved by the existence of fossil remains of aquatic and other animals on many mountains." This quotation from Draper's *Intellectual Development of Europe* shows that Avicenna, in spite of all his Arabian characteristics, had in his mental make-up a certain amount of objectivity not uncommon among other Arabian scientists of the Middle Ages. It anticipates by several centuries modern scientific observation of earth structure.

The key to Avicenna's influence is not that he surpassed all other Arabian physicians (Rhazes, Avenzoar, etc.) who dealt more or less incidentally with natural science, but that his *Canon of Medicine* became the recognized guide of medical study in European universities from the twelfth to the seventeenth centuries. So extensively was it used that the *Canon* was often spoken of as " the most famous medical text-book ever written." Along with Aristotle, Pliny, and Isidore, he is continually quoted as an authority by the encyclopædic writers of the thirteenth century. The most extensive and devoted commentator on Aristotle was Averroës of Cordova whose writings mark the culminating influence of Arab philosophy on European thought. " He developed the teachings of Aristotle upon lines that made a sharp division between religious and scientific truth, and so prepared the way for the liberation of scientific research from the theological dogmatism that restrained it both under Christianity and under Islam."

Averroës (ca. 1126–1198) was primarily responsible for placing Aristotle before the Christian schoolmen. Dante, in the Inferno, speaks of Averroës as "him who made that commentary vast," seated amidst "the philosophic train," in Limbo, which was reserved for the good and virtuous who from neglect of baptism were not permitted to enter Paradise. The reverence of Averroës for Aristotle amounted to a passion and he expounded the principles of Aristotle's philosophy with loving care. In his writings he tried to harmonize the teachings of Aristotle and Galen; when this was impossible, Galen was always sacrificed.

Fig. 12. — Averroës, ca. 1126–1198: From Raphael's Painting in the Vatican. (Popular Science Monthly, 1884.)

By a dignified, straightforward treatment of evidence, he helped to develop scientific method, then in its infancy. One of his methods of exposition was to quote a paragraph from Aristotle and then to expound it in his own words. But though the general habit of mind of his time was uncritical, and showed almost unquestioned allegiance to authority, Averroës displayed a judicial turn and a disposition to examine evidence carefully. Thus he aroused opposition and distrust; he was stigmatized as a free-thinker and an infidel, too often the fate of men in advance of their times. Averroës had a forward-looking mind, and only carried into practice that which others had theoretically expressed, that "He who would serve the cause of truth in science must be above all a free-thinker." [7] His advance was a step towards that critical, inquiring way of looking at nature which was so much needed, and through his followers among the

[7] Attributed to Ptolemy, the Astronomer.

scholastics, who heralded him as one of the masters of the science of proof, he produced a reaction against subjective thinking. But he had powerful opponents also. Erasmus spoke with contempt of scholastic barbarism with its "impious and thrice-accursed Averroës." It is known that he wrote Commentaries on Aristotle's *Natural History of Animals,* but these have not come down to us. His *Book of Universals,*[8] "an attempt to found a system of medicine upon Aristotle's philosophy, advanced the Pantheistic doctrine that the soul or nature of man is absorbed into universal nature at death. This denial of personal immortality caused Averroës to be persecuted in his own lifetime and his followers to be anathematized during the Middle Ages." (Garrison.)

Since the close of mediæval times the Arabians have shown no taste for natural science, and today are a very backward people in knowledge of natural science and medicine. This makes their part in the preservation and transmission of science to western Christendom the more extraordinary. "If the Greek was the father, then the Arab was the foster-father" of our natural science and it was through the Arab that this inheritance was passed along. The pure Arabians, however, were more receptive than productive, and it was necessary to have alien mental strains mixed with their own to produce the remarkable results noted above. Jews and Nestorian Christians played an important part as dispensers of intellectual treasures, and to a certain extent the keen, bright mind of the Arabians shone as by light reflected from them. The Moslem universities, which were developed in advance of those of western Christendom, were famous for instruction in philosophy, and they drew students from Christian countries. "At Cordoba, in particular, there were great numbers of Christian students, and the influence of Arabian philosophy coming by way of Spain upon the universities of Paris, Oxford, and North Italy, and upon Western European thought generally, was very considerable indeed."

Having played their part in preserving and transmitting an-

[8] "*Kitab-al-Kollyat* transliterated as *Colliget*" (Garrison).

cient science to Western Europe, the Arabians receded in intellectual importance, while the western people, endowed with greater originality and capacities for scientific investigation, went continually forward.

SUMMARY

The period just reviewed shows little advance in investigation of nature. The best minds of the Middle Ages were concerned with other matters, such as dialectics, metaphysics, ecclesiastical philosophy, while science was stigmatized as a product of pagan thought. The Christian Church acted as the foster-mother of culture and learning. Book multiplication was carried on in the scriptoria of monasteries; the collecting of books into libraries and reading by the educated were active. The method of reference to authority in matters of science and learning created an unprogressive attitude of mind against which a few more independent thinkers struggled. At intervals we encounter men of independent thinking, and in the twelfth century we get a glimmer of the scientific spirit in Adelard of Bath. The Saracens played a part in preserving and transmitting the manuscripts of classical antiquity, especially those on the science of nature and of medicine. They also founded great universities in Bagdad and Cordoba where learning prospered, but they were not a creative people fitted to carry on investigation of natural phenomena. Two Arabian physicians, Avicenna and Averroës, exhibited a spirit of inquiry and their writings had marked influence in the early founded universities of Western Europe.

CHAPTER VI

SOME NATURAL HISTORY WRITINGS OF THE THIRTEENTH CENTURY

The thirteenth century witnessed an outburst of the creative spirit in Western Europe, which showed itself in art, in architecture, in literature, in education, and to a limited degree in science. These manifestations of creative endeavor had been a long time in preparation, and the various movements which came together, making the thirteenth century one of the most notable of all history, were the culmination of two centuries of mediæval progress. The infusion of scientific knowledge from Arabian sources, mentioned in the last chapter, had been one of the influences in this progress, but there were several others, some of which will be mentioned.

THE CRUSADES

During the twelfth century, the people of Western Europe had been stirred by a great thought and bound together in a common cause. The purpose which animated all Christian society of the West was to rescue from the Moslems the control of the Holy Sepulchre and other sacred places of the East and restore them to Christian hands. This led to the Crusades, which at intervals from the eleventh (1096, First Crusade) to the thirteenth century drew Western Europe to the East. The general effect was far-reaching; the general condition of society was improved, commercial prosperity was promoted, and the foundations were laid for community of action which resulted ultimately in the overthrow of Feudalism. The intellectual awakening, however, was perhaps the greatest of all the results of the Crusades. The circulation attendant on these expeditions set in motion currents of thought which had become stagnant. Lib-

eralizing contact with new scenes, new ideas and higher standards of civilization, the sense of adventure and the excitement of new experiences, all helped to expand the horizon of men's minds. Nor was this renovation and extension of ideas confined to the educated and the favored few but reached down into the masses, so that the people as a whole were mentally stimulated and began to show an eagerness for knowledge.

The Crusades although helpful were not an indispensable factor to the development of the new spirit; they merely hastened the movements already in operation.

There were certain generic influences helping intellectual development at this time and these we must consider, as well as the specific influences which related directly to natural history, and which were only an accompaniment of the general forward movement.

ART AND LITERATURE

To establish a perspective and to get an idea of the universality of the progress in the thirteenth century, we need only mention a few names and a few events. In art, Giotto (1266–1327) was the peer in creative genius of the later artists. In architecture, we have the construction of Gothic cathedrals which are the admiration and the despair of succeeding generations. Whether considered from the standpoint of elevated conception of design, of perfection of workmanship in artistic stone-cutting or stained glass, they have never since been equaled and stand in the first rank of human achievement.

In literature, the century was the seed-time of the national literatures of Western Europe. Long-current legends and stories of knight and king, love songs of students and wandering minstrels, and other half-artistic, popular expressions of human longing took a more definite expression in the thirteenth century and were reduced to writing. Mention of the Arthurian legends, the Cid, the Romance of the Rose, and the Nibelungen-Lied will recall the type. Above all, we have the imaginative creations of Dante (1265–1321), to be followed in the next century by Petrarch, Boccaccio, and Chaucer.

Universities. Education took a forward step in the more definite organization of faculties of instruction in the universities and in the better adaptation of the curricula to growing demands. The universities of Salerno, Bologna, Padua, Paris, and Oxford had been founded earlier, but in the thirteenth century the attendance at the universities became very large and created new demands. Rashdall, in his *Universities of Europe in the Middle Ages*, tells in detail of their founding, and Walsh, in *The Thirteenth, the Greatest of Centuries,* assembles some interesting facts regarding the number of students. The attendance in relation to the total population was very large. According to Walsh there were, near the close of the thirteenth century, about twenty thousand students at Paris, nearly an equal number at Bologna, ten thousand at Oxford, and some thousands at Cambridge. The population of England at the time was approximately three million. If we figure on ten thousand students to a population of three million, we get a ratio not far from that which was obtained in 1914 in the colleges and universities of the United States.[1] Among the outstanding figures were Thomas Aquinas (ca. 1227–1274) in theology and scholastic philosophy, and Albertus Magnus (ca. 1206–1280) and Roger Bacon (ca. 1214–1294) in science.

We cannot make more than passing mention of certain ideas which were dominant in the later Middle Ages and after the Renaissance, but which either became obsolete or contributed nothing to intellectual progress. They spring to mind at once when we speak of Scholasticism; among them are the famous ideas of macrocosm and the microcosm, the systems of the realists and nominalists. To treat of them specifically would involve digression, however interesting, from the path along which natural history has developed.

KNOWLEDGE-BOOKS

The eagerness for knowledge manifested in the thirteenth century was supplied by certain famous "knowledge-books"

[1] See *Chicago News Almanac,* 1914.

summarizing all there was then known about animals, plants, and minerals. These knowledge-books were huge encyclopædic writings which, by compilation, citation, and comment, represented the contents of whole libraries in an age when reference libraries of many books were uncommon. Some of these knowledge-books contained original observations on natural history in addition to the citations from authorities, for contrary to a widespread belief there was considerable study of nature in the mediæval universities.

The knowledge-books or encyclopædias were characteristic productions of the thirteenth century; within a quarter-century (1230–1260) four of them appeared and played their part in the general diffusion of knowledge. These four were prepared independently by Vincent of Beauvais, by Albert the Great, by Thomas of Cantimpré, and by Bartholomew of England. Naturally, they were all of large size, that of Vincent being the most vast as to design and execution; that of Albert had the greatest influence on the natural science of the century, and, to judge from recent investigations,[2] it seems likely that the *Properties of Things* of Bartholomew was the most widely circulated.

ALBERT THE GREAT

Since the work of Albert had the greatest influence, we shall first give an account of it, and then deal with the others in less detail. Albertus Magnus (1206–1280),[3] a descendant of a noble family (he was count of Bollstädt), was unusually gifted, mentally. He was great as a teacher, as a philosopher, as a theologian, and as a naturalist. His extensive writings were assembled by Jammy in 1651 in twenty-one folio volumes, and reproduced by Borgnet and published, in thirty-six volumes in Paris in 1890. Disregarding his other writings, we shall give attention only to his treatise on nature (*Opus naturarum*), and, especially, to those parts on animals (*De animalibus*) and on plants (*De vegetabilibus*). Except that they were issued somewhat after the

[2] See Boyer, *Bartholomæus Anglicus and his Cyclopædia.*

[3] The date of Albert's birth is uncertain, being sometimes given as 1193.

year 1250, the date of these works is undetermined. From his own statements we know that Albert had a natural inclination towards the study of nature; apparently Augustine and Aristotle were his favorite authors. Albert's writings on animals contain some observations of his own, but De Blainville and Pouchet have made too much of these, and we must agree with Carus that he displays little critical ability in this direction. It would be difficult to name a single animal of which he has given the first adequate description. Meyer's praise of his botany seems to be more justified.

ALBERTVS MAGNVS EPISCOPVS RATISPONE
Magnus es, ut major fieri Alma ALBERTE, queamus
Dispeream, si quid magius hic orbis habet.

FIG. 13. — ALBERTUS MAGNUS, CA. 1103–1280. (Walsh, Catholic Churchmen in Science, Series two.)

In his descriptions Albert uses a simple, straightforward manner. Here is an example, in which he makes no quotations and relies entirely on his own observations: "The ostrich (Struthio) is a bird of the Lybian desert, but more often seen (by Europeans) in our country. In youth it is ash-colored, and completely feathered, but the feathers of its wings are not strongly developed; in its second year, and thereafter little by little, it loses completely the feathers of the thighs, neck, and head, exposing the body; it is protected, however, from cold by tough skin; and the very dark feathers of the back become as it were like wool. The very strong hips and the fleshy legs have white skin, and the toes are arranged in the foot like a camel's; it is called *camelon* by certain Greeks, and *asida* by others. Moreover, it is tall, perhaps five or six feet from foot to back; it has a very long neck, a goose-like head, and a beak quite small, as compared to its body. It is said of this bird that it swallows and digests iron; but I have not

proved this myself because several ostriches refused to eat the iron which I threw them. However, they eagerly devoured large bones cut into small pieces as well as gravel (*lapides*).

"This bird is said to be bound to the earth (*stolida*), and unable to fly, but by extending its wings it somewhat hastens its course. It has certain spurs in the elbow of the wings with which it strikes whatever it attacks. This bird lays in July and hides its eggs in coarse sand (*sabulo*) and these hatch in the heat of the sun, just as do many other eggs of animals; and the ostrich does not return to the eggs, because its naked body is not able to incubate them. Sometimes, however, it guards them, keeping watch over the place where they lie; and for this reason a false rumor has gone forth that it hatches its eggs by looking at them. These are the things which I have observed about the ostrich, which seems to me not so much a bird as a creature half way between a walking and a flying animal." [4]

In Borgnet's edition of the complete writings of Albertus Magnus the part on animals occupies twelve hundred and forty quarto pages of text. Only two hundred eighteen pages are devoted, however, to actual description. The rest is made up of generalizations on the common ways in which animals are found to differ from each other and similar subjects.[5] It constitutes a pretty thorough paraphrase of Aristotle, but most of it is obsolete and makes very tedious reading. He says at the end of his preface: "Therefore, we complete our description of animals in twenty-six books, in chapters orderly arranged, and, augmenting that which was well arranged by Aristotle in seven books, transmit to posterity the whole science in logical sequence."

Meyer estimates Albert's contribution to botany very highly. He says, "considering the lack of means of research such as the

[4] *De Animalibus*, Lib. XXIII, Tract. unicus, p. 502.

[5] Albert treats of a larger number of animals than Thomas of Cantimpré or Konrad, his German translator. He includes four hundred seventy-five (including some duplications under different names), Konrad has two hundred fifty-eight, and Thomas in some manuscripts four hundred fifty-one. The descriptions (or comments) are stronger than those of Thomas — more conscientious — more thorough. The treatise of Albertus is distinctly a stronger piece of work than that of Thomas of Cantimpré or of Konrad, his German translator.

microscope, knowledge of chemistry, and the practice of experiments in Albert's time, that little remains in Botany that he did not see and understand as well as or even better than his followers for some three centuries." He was surpassed by Aristotle and Theophrastus and by Caesalpinus, but between Theophrastus and Caesalpinus Meyer thinks there is no one to compare with Albert as a botanist. To subscribe fully to this estimate would be to overlook Crateuas, whose illustrations show that his observations of plants must have been very acute. Also some of the elaborations of the Dioscorides manuscripts, such as the Julia Anicia codex, show capable observation of plants. Albert was not acquainted with the writings of Theophrastus but he made use of a spurious work ascribed to Aristotle and which he supposed to be genuine.

Albert's botanical work was spoken of disdainfully by Haller and by Sprengel, but there is reason to believe that both men were unacquainted with his writings on plants, and that they used only an inferior work entitled *Liber de vertutibus herbarum, lapidum et animalium,*[6] attributed to Albertus Magnus but of uncertain authorship.

It was perhaps Albert's greatest service to the progress of science that he made Aristotle's natural history palatable to the ecclesiastics. The high opinion in which he was held by the clergy enabled him in this matter to build better than he knew.

We must not think that Albert's attempt to restore the natural history of Aristotle to favor was the first of its kind in the Middle Ages. Already in the twelfth century Neckam, in his *De naturis rerum* (1170) had unrestrainedly placed "the most acute Aristotle as the pre-eminent authority among all philosophers." Neckam cites Aristotle's *Historia animalium* and, as pointed out by Thorndike, this throws doubt on the accuracy of the oft-quoted passage of Roger Bacon to the effect that the works of Aristotle on natural philosophy were first introduced to the mediæval Latin learned world in Latin translations by Michael Scot about 1230.

[6] *Liber aggregationis:* See Thorndike, vol. 2, pp. 722–723.

Pouchet heralds Albert as the beginning of the experimental school,[7] but this conclusion is scarcely justified. We have seen that Galen, eleven centuries earlier, had been a truly great experimenter, whereas the actual experiments of Albert were most meager. Albert undoubtedly glimpsed the need of experiment in science, but was circumscribed by the state of knowledge in the thirteenth century. In his treatise on plants he says "experiment is the only sure method in such investigations"; the wording of the original Latin is strong: "*Experimentum solum certificat in talibus.*" But we must remember that expressions of similar import were not uncommon in classical writers, and Albert's "experimentum" meant no more to him than "personal experience" to us. It cannot be translated "experiment" as that word is used in science today. Nevertheless it exhibits a mental attitude which heralded if it did not initiate the modern era. In his book on minerals he says: "The aim of natural science is not merely to accept the statements of others, but to investigate the causes that are at work in nature." If he was not the initiator of modern scientific methods, he was the forerunner, by three and one-half centuries, of that Francis Bacon, who stated so clearly the need of experimental results while doing so little to obtain them.

Though he appreciated, as we have seen, the objective point of view, he was so saturated with the philosophy of scholasticism that in practice he himself could not get away from one of the hindrances imposed by that philosophy on all would-be scientists, namely, the ingrained belief in the mystical union of the natural and the spiritual world. But before constructive advances could be made in science there was need of a clear discernment of its proper field. The conception of the material world as the arena of investigation was needed to make knowledge realistic and to remove the fog of mysticism which obscured all investigation of nature. Albert's promoting of Aristotle at this time helped greatly in a movement carried on by such materialistic

[7] Albert le Grand et son époque considérés comme point de départ de l'école expérimentale.

thinkers as Peter of Abano (1250–1315?),[8] and experimenters and observers like Roger Bacon and Nicholas of Cusa.

Albert was thoroughly in touch with the educational progress of his century and it is interesting to learn that he, in collaboration with St. Thomas Aquinas and Peter of Tarentasia (afterwards Pope Innocent V) represented the Dominicans on a committee for the revision of studies in Dominican schools. The committee thoroughly considered methods of teaching and requirements for graduation, with a view to making the graduates from Dominican schools in every way the equals of graduates from the universities.

While Albert was in close touch with the constructive forces of his century, the time was not ripe for the renovation of science and learning; he succeeded only in restoring the science of the past, whereas the crying need was the making of new knowledge. Steele's statement,[9] however, "Summing up our impressions, his influence on his time is on the whole bad," is too severe. This does not sufficiently recognize Albert's independent work in botany, his attempts towards the improvement of education, and his influence in making Aristotle's philosophy of nature current and acceptable to the ecclesiastics.

Cyclopædia of Vincent. Vincent of Beauvais (ca. 1190–ca. 1264), like Albert a Dominican, wrote the most extensive cyclopædia of the Middle Ages. Although we cannot discern that it had much effect on the progress of natural history, it was a famous reference book, and must be noticed on account of its fame and its rather extensive treatment of animals, plants, and minerals. It was a vast compendium of all available knowledge. Under the general title *Speculum majus* (also, *Imago mundi*) it was divided into three parts: [10] — *Speculum naturale; Speculum historiale;* and *Speculum doctrinale* — to which a fourth part — *Speculum morale* — was added by another hand (in the printed editions the fourth part is always included). This vast cy-

[8] He died between 1315–1318: See Thorndike, vol. 2, pp. 933–934.
[9] *Studies on the History and Method of Science,* 1921, Vol. II, p. 135.
[10] Though each part is a distinct work by itself.

clopædia was the product not only of Vincent but of a number of collaborators and assistants working under his supervision; indeed the citations are so numerous that they could scarcely have been assembled by one man. It was prepared at the command of Louis IX of France, who provided assistants and placed at Vincent's disposal the Royal Library, said to have contained twelve hundred manuscripts. In the *Speculum naturale* alone Vincent mentions about three hundred fifty separate authors from whom he had drawn material. In the whole work there are citations from about four hundred and fifty different authors. Apparently, the design of this great work was Vincent's own, though in his order of treatment he follows Thomas of Cantimpré and borrows much from him in those parts relating to natural history.

The great bulk [11] of Vincent's cyclopædia can be realized from the fine edition printed in Strassburg, 1472–1476, in eight volumes containing 4542 large folio printed pages. It is more extensive than Pliny's *Natural History*. It is in a way the forerunner of the French *Encyclopédie* which appeared under the combined auspices of a number of brilliant scholars some five centuries later.

The book is purely a compilation, however, without a trace of original or even critical work by Vincent himself. In this regard it is inferior to the work of Albert. Its only value in connection with natural history arises from the fact that it reproduces nearly everything written up to that time about animals and plants. But it is not to be thought that the thirty-two books of the *Speculum naturale* are chiefly devoted to animals and plants. Such topics as creation, angels in heaven, light, color, the four elements, Lucifer and other fallen angels, the phenomena of the heavens, time, sky, fire, rain, thunder, dew, winds, geog-

[11] The enormous size of Vincent's *Speculum* was an obstacle to its reproduction either in MS. or in print. A complete copy of the Strassburg edition, mentioned above, is in the Pierpont Morgan Library, New York City; evidently this is more extensive than the edition used by the author of the article on Vincent in the Encyclopædia Britannica, who speaks of the *Speculum naturale* as having eight hundred and forty-eight closely printed folio pages. The same in Mr. Morgan's copy has thirteen hundred and ninety folio pages in two ponderous volumes.

raphy, astronomy, moon, stars, zodiac, sun, planets, seasons — and many other topics of a general nature occupy the major part of the space.

Animals and plants are discussed chiefly in six books. Here Vincent quotes often from Aristotle, the Bible, Pliny, Solinus, and Isidore of Seville. He also quotes from Physiologus, and the usual Arabian and western medical writers, such as Avicenna, Rhazes, Galen, Dioscorides, etc. His scope of topics and authors represents fairly well the character of the mediæval encyclopædia — though Thomas of Cantimpré devotes a large portion of his *De naturis rerum* to animals and plants and Bartholomæus Anglicus, in *De proprietatibus rerum* is also much more devoted to natural history than is Vincent.

BARTHOLOMEW OF ENGLAND

Bartholomæus Anglicus was an English Franciscan who flourished during the first half of the thirteenth century. Considerable confusion exists in catalogues and reference books regarding his date and family. It is well established, however, that he was not Bartholomæus de Glanville who lived in the fourteenth century. According to recent views based on first-hand study, he was probably born in England about 1190, was educated at Chartres and Paris, lectured at Paris, and about 1231 went to Magdeburg where he both taught and helped to direct the work of the Franciscan order in Saxony. It is probable that he died shortly after the middle of the thirteenth century.

His cyclopædia entitled *On the Properties of Things* (*De proprietatibus rerum*) [12] was the most popular of the thirteenth century encyclopædias.[13] Although its scope was wide, the book itself was not too voluminous, and it met the needs of the increasing number of readers " without exhausting their patience."

[12] Among the more recent studies of Bartholomæus and his cyclopædia, those of SeBoyar (Journal of English and Germanic Philology, 1920) and Thorndike (History of Magic, 1923) are to be commended.

[13] More than a hundred manuscript copies in Latin (mostly of the fourteenth century) are known in European libraries. Before the year 1500, it had been translated into six modern languages — French, English, Spanish, Dutch, Provençal and Italian.

Bartholomew " states the character, purpose and scope of his work at its beginning and again in closing." Although " simple and crude," " he hopes it will be useful to persons who, like himself, are not advanced students." He speaks modestly of his work as an elementary treatise, textbook, or work of reference for the benefit of " young scholars and the general reader, who because of the infinite number of books cannot look upon the objects of which Scripture treats, nor are they able to find quickly even a superficial treatment of what they are after." [14] By the year 1286, it was listed at the University of Paris among the books loaned out to students, and there was also a copy chained to the desk at the Sorbonne.[15] After 1470 it was printed, and not less than forty-three printed editions have been identified. The fine Dutch edition of 1485 (*Van den Propieteyten des Dinghen*) [16] is of special interest to us because it contains eleven full-page folio woodcuts all printed as inserts. The copy of this issue in the Pierpont Morgan Library of New York, derived from the library of William Morris, has the cuts colored by hand. The figures of animals, both as to woodcutting and design, in this Dutch edition are much superior to those in the English edition, whereas the woodcuts of the English translation, printed by Wynken de Worde, about 1495, are wretched caricatures of animals and plants — some of them being degraded copies of the pictures in Megenberg's *Buch der Natur,* 1475; those of the Dutch edition referred to (Fig. 14) are among the good pictures of the period.

The English translation was made by John Trevisa in 1398, and when printed nearly a hundred years later was entitled *Properties of All Thynges.* In the text Bartholomew adheres pretty closely to the nature of *things;* not all things, he says, but only those of which holy writ " makyth remembraunce." In reference to beasts, in Book 18, Bartholomew says he treats of those things that have " lyfe and felynge." [17] " Of all beasts tame and wild, of all worms that creep on the ground; and

[14] Thorndike, *op. cit.* [15] See Se Boyar, *op. cit.*
[16] Haarlem, Ballaert, 1485. Copy in the Pierpont Morgan Library.
[17] Trevisa's translation, p. 701 (Pierpont Morgan Library).

fyrste in generall and after in specyall." And all that is "comprehendyd of fleeshe and of spyryte of lyfe," and so of body and soul is "callyd animall." Accordingly, we are not surprised to find Bartholomew treating somewhat of psychology. But he treats only briefly and incidentally of the medical virtues of animals and plants, so that we cannot look on his book as primarily a book of folk medicine, as some writers have maintained we should. Trevisa's translation became the chief source from which Shakespeare and other Elizabethan writers drew their knowledge of nature.

It is very difficult to estimate the influence on science of any of the thirteenth century encyclopædias, but I cannot avoid the impression that Carus in his history of zoölogy, has underestimated the influence of Bartholomew in the dissemination of scientific knowledge. We can scarcely say that any of the cyclopædias of the period exercised much direct influence on the improvement of natural history. Carus allows to Thomas of Cantimpré much greater influence, and says the work of Bartholomew contributed nothing to progress. As a much clearer exposition of the scientific knowledge of the time, and by its wider circulation, I believe the advantage rests with Bartholomew. No one can read corresponding passages regarding animals and plants in Bartholomew and Thomas without recognizing that Bartholomew's is a better piece of work. Bartholomew shows a greater degree of assimilation of his authorities, he is fuller in his citations and more systematic than Thomas and his German translator, Konrad von Megenberg. The citations of Thomas impress one as hurried and superficial, those of Bartholomew as thoroughly digested. In addition to direct citations, Bartholomew often gives a paraphrase in his own words and shows a more thorough mastery of his sources than does Thomas. It was perhaps as well, therefore, that, as already mentioned, Bartholomew's cyclopædia was the principal source of scientific knowledge for the Elizabethan writers, through whose works references to the science of nature gained access to the vernacular literature.

THOMAS OF CANTIMPRÉ

The cyclopædia of Thomas of Cantimpré (*De naturis rerum*), given to the world about 1250, was translated into German about one hundred years after its first appearance. This translation was by Konrad von Megenberg who called it *Das Buch der Natur*. It was first printed in 1475 and contained the earliest printed illustrations of natural history. On this account it will be considered in a later section where we take up printed illustrations and their influence on the progress of natural history. The original Latin of Thomas has never been printed.

To avoid misconception, it should be remembered that the cyclopædia was a very old form of writing. Pliny's Natural History, prepared in the first century A.D., is the earliest that has come down to us; then we have Capella (fifth century); Cassiodorus (sixth century); Isidore of Seville and others less notable; then, Neckam in the twelfth century. These cyclopædias were all in Latin. In France in the twelfth century there were a number of cyclopædias written in French under such titles as *Miroir du monde*, *Image du monde*, etc. The title of the great cyclopædia of Vincent of Beauvais *Imago mundi*, or *Speculum majus*, had been used before.

The cyclopædias of the thirteenth century helped spread knowledge regarding animals and plants. Albert the Great made Aristotle's philosophy of nature palatable to the Church, and Bartholomew came very near making natural history popular. These were preliminary steps to the liberation of natural history from the bonds of scholasticism. Still, as pointed out above, what was needed was that the phenomena of the material world should be separated from the mystical interpretations of the scholastic philosophy. This step was taken in the following centuries and when once the material world, with its unlimited possibilities, was recognized as the proper field of investigation, the advancement of science received a new lease of life.

CHAPTER VII

THE EARLIEST PRINTED ILLUSTRATIONS OF NATURAL HISTORY

In chapter two the remarkable pictures of animals by Crô-Magnon artists were dealt with showing how accurately these prehistoric people observed living nature. As we come into historic time, animals continued to be favorite objects for representation. On Minoan cups, and on vases of classical antiquity, are to be seen many representations of animals, and some of plants. The animal figures show closer observation, the plant figures being conventional and inaccurately drawn. Representation of animals is frequent on Assyrian walls — especially the oft-repeated pictures of the lion, of lion hunts, even of Assyrian warriors going out to fight with lions, which it appears were a menace to public safety in those times.

In ancient and mediæval manuscripts illustrations of animals and plants are abundant, sometimes exquisitely drawn and colored. We have in this form a succession of plant pictures beginning with the sixth century A.D., and continuing as late as the invention of printing and even later. The pictures illustrating the Dioscorides manuscript, prepared at Constantinople about 512 A.D.,[1] became the prototype of those in many succeeding manuscripts. The Paris codex of Dioscorides of the ninth century, the Phillipps MS. of the tenth century, etc., show derivatives more or less changed of these early plant pictures. In other less pretentious manuscripts these pictures, reduced in number, were conventionalized and degraded until they became traditional figures with little resemblance to the plants they were supposed to depict. The succession of plant pictures in manu-

[1] See Chapter IV.

scripts covering a period of a thousand years affords material for a history of botany from the sixth to the sixteenth centuries.[2]

Several manuscripts of the Physiologus and of Bestiaries in European libraries contain illustrations of animals. In the Pierpont Morgan Library of New York there is a bestiary of 1170 with some beautifully illuminated sketches of animals.[3] This manuscript of two hundred forty pages and one hundred six figures is one of the finest in existence. The text is more complete than that of any other known bestiary and supplies in some points the unknown Latin original of the old French Bestiary of Philip of Pecard.[4]

Anatomical sketches in mediæval manuscripts, showing the structure of some parts of the human frame, have been traced from the ninth century. They are, however, very rude and primitive and do not approach the fine quality of some of the plant pictures. These anatomical sketches were copies from manuscript to manuscript, altered and conventionalized until there arose traditional Figures upon which the early illustrations of anatomy were based.

We pass now from the era of manuscript pictures to that of the earliest printed illustrations of natural history. The introduction of printing in the middle of the fifteenth century was contingent on a sufficient supply of paper and making it cheap enough for general use. This new method of multiplying books began at once to exercise an invigorating influence on the intellectual life of the world. The stream of knowledge "ceased to be a little trickle from mind to mind; it became a broad flood, in which thousands and presently scores and hundreds of thousands of minds participated." [5]

Of the books printed between 1450 and 1500[6] probably

[2] Examples of this long series of plant illustration in manuscripts have been published by Charles Singer in Volume II of *Studies in the History and Method of Science*, 1921.

[3] That of the bear and her cubs is very beautiful and touching, showing the tender solicitude of the mother bear for her offspring. The colors are a fine blue on a gold background.

[4] See *Lauchert Ges. der Physiologus*, 1889, p. 103.

[5] Wells, *The Outline of History*, Vol. 2, p. 159.

[6] The books printed in the fifteenth century — ca. 1450–1500 — are called

eighty per cent were religious and scholastic. The early publishers found ready at hand the highly venerated classics of antiquity, as well as those of the Middle Ages, and for the most part were content to issue these in printed form. Only a few books were freshly prepared during the period. Three of these, Conrad von Megenberg's *Buch der Natur,* 1475; the *Garten der Gesundheit,* 1485; and the *Hortus sanitatis,* 1491, should be mentioned here as they have sections on animals and plants as well as on other topics. In fact, each may properly be spoken of as a Book of Nature, and the *Hortus sanitatis,* as both a Book of Nature and Book of Folk-medicine. The extent of treatment of the different topics in the three is not uniform; the first deals more extensively with animals, the second with plants, and the third more comprehensively than the other two with both animals and plants.

Frequent misstatements in regard to these books by some of the most esteemed writers of the history of natural science make it advisable to deal with them here more in detail than would otherwise be called for.

In 1475, soon after the completion of the first quarter-century of printing, there appeared in Augsburg a popular book on natural history illustrated by woodcuts of animals and plants, some of which bear internal evidence of having been drawn

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" incunabula " and they have been more carefully listed than the books of any other corresponding period. Hain's great Repertorium of fifteenth century books mentions approximately sixteen thousand issues or editions; Copinger supplements this with seven thousand new titles, raising the various editions of incunabula to twenty-three thousand, and the new Repertorium begun in 1905, by the German Government, bids fair to bring the number up to thirty thousand. Estimates vary as to the total number of books of all kinds issued by the forty printing presses of various countries up to the year 1500. Robinson, in *Medieval Times,* gives an estimate of eight million volumes, and W. A. Pollard, in the *Encyclopædia Britannica,* suggests a possible total output of twenty million volumes. The greatest collections of incunabula are in London, Paris, and Munich — the British Museum and the Bodleian Library of Oxford possessing between them as many as ten thousand separate incunabula. The recent " Census of Fifteenth Century Books Owned in America " shows six thousand six hundred forty titles distributed among four hundred fifteen owners — one hundred sixty-nine public libraries and two hundred forty-six private collections.

from nature and of having been especially prepared for this book. Under the archaic title *Das Buch der Natur,* by Conrad von Megenberg, it was a thirteenth century German translation of the Encyclopædia of Thomas of Cantimpré. Though not genetically connected with any later publication, it seems to have served as a model for other illustrated books of similar purpose which were published in Germany within the next ten or fifteen years. We know that it passed through six editions before 1500 and enjoyed a wide circulation; we might even speak of it as one of the best sellers of the period.

Another book, the *Garten der Gesundheit* (*Herbarius zu teutsch,* etc.) published in Mainz in 1485, surpasses, in the quality of its illustrations, all other books published up to 1530, the date of the appearance of Brunfel's illustrated herbal. This statement is so much at variance with the commonly expressed opinion of well-known writers of biological history (Sachs, Greene, Miall, Thomson, and others) that it seems desirable to reëxamine the originals of each of these books from the standpoint of content and quality of illustrations. This will be done after a few generalizations concerning these books and other printed books of the time.

The original illustrated editions of the *Buch der Natur* and the *Garten der Gesundheit* are very rare and have been accessible to few naturalists. One bibliographer, Dr. Jos. Frank Payne, has (1902) discerned the unique position occupied by the *Garten der Gesundheit,* "the publication of which (he says) forms an important landmark in the history of botanical illustration, and marks perhaps the greatest single step ever made in that art. It was not only unsurpassed but unequaled for nearly half a century." Dr. Payne does not comment on the few pictures of animals in the *Garten der Gesundheit* but they are equally notable. Other writers also, as Mrs. Arber (in her book *Herbals*) have been well aware of the superior quality of some of the pictures of plants in the *Garten der Gesundheit.*

Neither of the books has received the notice it deserves. Attention has been diverted from them by the notice given to

the *Hortus sanitatis,* with which they have been confused. The *Hortus sanitatis,* published at Mainz in 1491 and in many editions thereafter, belongs to the same family of publications as the *Garten der Gesundheit.* Its size, its numerous illustrations (1066), its later date of publication and its great popularity, have naturally led to the assumption that it represents the highest development of its type. It has been thought that the *Hortus sanitatis* was the Latin translation of the *Garten der Gesundheit* and that the degraded illustrations of the *Hortus* were at least as good as any printed before the famous illustrated herbal of Brunfels.

But the *Gart*[7] (1485) not only antedated the *Hortus sanitatis;* it is superior to it in several particulars, especially in the quality of some of its illustrations, which were drawn from nature. Together the *Buch der Natur* and the *Garten der Gesundheit* represent a forward trend of the human spirit and should be given attention commensurate with this fact. If ever we are able to gauge the thought-life of the later Middle Ages, and especially of that interesting period of intellectual development just preceding the full bloom of the Renaissance, it must be accomplished by a study of the publications of the period. Let no one assume that these books are merely curiosities of antiquarian interest. Though the books of the time which have claimed most attention from scholars show a different phase of mental life and betray the attitude of the mystical-minded scholar and the subjective theologian, while Conrad's book, as well as the *Gart,* represents the more objective or scientific attitude of mind, we must remember that these two currents of mental life still ran parallel at this time, even if the subjective was the more conspicuous. The scientific attitude, though undeveloped and even primitive, was still real.

The reading matter of the period, however, was more diversified than one might at first suppose. Besides Bibles, books of devotion, the famous *City of God* of Augustine, and other religious writings, a reader of the period found at hand printed

[7] For the appropriateness of this abbreviated title, see below.

copies of legal treatises and other secular writings of various sorts. Dante, Petrarch, Boccaccio, Chaucer, Æsop's fables, the Bidpai stories (showing affinities with the Arabian Nights), Breidenbach's travels, the Dialogues of the Creatures, Reynard the Fox, The Romaunt of the Rose, etc., were all available outside the scientific field, which was embodied in medical treatises and nature books.

Also dealing with nature (as well as other subjects) were such writings as the huge encyclopædias of Vincent of Beauvais, the *Properties of Things* by Bartholomæus Anglicus, etc. Furthermore, it should be remembered that the printing presses were turning out on a relatively large scale the remains of classical and early mediæval learning. Among these may be mentioned the scientific writings of Aristotle, Theophrastus, Pliny, Dioscorides and Galen. Reading had become general, and there was no lack of printed matter to suit all tastes.

But the book publishers of the period, desirous to stimulate a wide market for the sale of their wares, did not depend wholly on curiosity and mental interest. In the Latin preface of the *Hortus sanitatis,* published 1491, there is a clever appeal to the commercial instinct. The writer, or compiler, says that he has been moved first and foremost by compassion for the poverty of those sufferers who have not the means to hire doctors and apothecaries and that by the teachings of the book, these persons " with quite small expense to themselves will be able to compound helpful remedies and perfect medicines." This gives it the character of a book on popular medicine.

Another feature had more influence on the thought of the time. By pictures and descriptions the attention of the people was directed to the productions of nature, and information was spread regarding animals, plants, and minerals. As Klebs says, " almost the entire structure of modern (biological) science rests on such humble beginnings." " These books gathered what the monastic student had ' milked,' often uncritically, from the brain of the ancients and added comments and observations of their own. These additions mark the onset of inductive science."

CONRAD VON MEGENBERG'S *BÛCH DER NATUR*

As we have seen, this nature book was a German translation with some changes from the Latin *De naturis rerum* of Thomas of Cantimpré. The original was completed by Thomas about 1248 and translated by "Cunrat von Megenberg" a hundred years later. It was a complete review of nature and in this sense similar to the other cyclopædias of the Middle Ages. The German translation existed in manuscript for one hundred twenty-five years before it was first printed in 1475.[8] That it was popular and widely circulated is attested by the numerous manuscript copies in existence. Pfeiffer mentions seventeen copies of the German translation in the library at Munich, eighteen are reported from Vienna, and many copies are known in other continental libraries. In its printed form the book is now very rare.[9]

The short foreword, which was probably inserted by the publisher, telling the scope and the source of the book, is as follows: "Here follows the book of nature which treats first of the peculiarities and nature of man, then of the nature and the properties of the heavens, of beasts, of birds, of plants, of stones and of many other natural things. And upon this book a highly learned man worked for fifteen years, collecting for his use from the following named sacred and secular teachers, poets and other approved doctors of medicine, such as Augustine, Ambrosius, Aristotle, Basil, Isidore, Pliny, Galen, Avicenna, etc., and many other masters and teachers. Out of these and others he read, made excerpts and compiled the book. Which book Master Conrad von Megenberg transferred from Latin into German and wrote it out. Here is useful and entertaining material from which every man can learn many unusual things."

[8] There is another edition of 1478.

[9] There are two copies of the first (1475) edition in the United States, both in the Pierpont Morgan Library at New York. Through the courtesy of Mr. Morgan and his librarian I have had opportunity of examining these books and taking photographs of the plates.

Among the several other authorities cited in the book but not mentioned in the preface is the Physiologus.

Conrad, the translator,[10] was a cleric and teacher, who after various vicissitudes of life became Canon at Regensburg. Evidently he was a lover of nature; he had written a book on the world (Sphæra) and another on the *Gestelt der Welt*. In translating the *Book of Nature,* he says he rearranged and made additions as well as omitted some points. Indeed, some of the manuscripts of Thomas contain an account of one hundred and ninety-three animals not found in the translation[11] but there still remain two hundred sixty-seven animals commented upon. He seems to have improved and added to the plants.[12] From time to time he makes original comments, either expressing doubt of some statement, or adding a remark of his own — introducing what he has to say by " I also Megenberger say " but these comments are not of much importance.

A complete copy of Conrad's book should contain two hundred ninety-two folio leaves and twelve plates of woodcuts.[13]

The descriptive part of the book is disappointing. The art of description rests on good observation, and at this period independent observation had not been developed. The text is chiefly a series of brief quotations from the writers of classical antiquity and the Middle Ages — Avicenna and Averroës (1198) being among the most recent. The excerpts are mainly folk-

[10] Probably Conrad's translation was not made directly from the text of Thomas, but, as Haupt has claimed, from a working over and rearrangement of Thomas by Bishop Albert of Regensburg (Professor Thorndike dissents). Evidently the manuscript used by Conrad did not contain the author's name since he expresses doubt as to his identity, " Whether Albertus Magnus or not, I do not know." The source of the book, however, is now well authenticated.

[11] Carus, *Geschichte der zoölogie.*

[12] Meyer, *Geschichte der Botanik.*

[13] The two copies of 1475 which I have seen in the Pierpont Morgan Library are rather handsome volumes as to format and printing. They were derived from the library of William Morris. Each copy contains the twelve folio plates and is nearly complete as to text. This is something notable since Hugh William Davis says that five of the plates are missing in the copy of the first edition in the British Museum. All the cuts of both books in Mr. Morgan's library are colored alike in detail; accordingly I presume that they were both done by the same hand or that there was a conventional type of coloring prevailing at that time.

stories and trivial observations about animal behavior. The book is comprehensive in range but the largest part of it is devoted to animals. In relatively brief compass, the text preserves for us the mediæval lore about animals, plants and stones, but it is not descriptive science. I have not found a systematic or methodical description of any animal, but quotations beginning " Aristotle says," " Pliny says," etc. A few authors are cited under each title. Habits and behavior are spoken of, but there is no description of appearance, color, form, etc. Among flowers, rarely is the color of the flower mentioned (as frequently it is in the *Gart*). The comments on particular objects vary in length from seven lines up to two or three pages. Frequently one account occupies from one-quarter to one-half a page.[14]

Each of the twelve parts into which the book is divided is preceded by a general introduction in which one often finds moralizations and expression of theological views. In various places Conrad makes uncomplimentary allusions (common in mediæval writings) to the profligate priests (*üppigen Pfaffen*) who " like the ass are weak when they should carry the cross, and strong when they are unchaste." The Bishop is compared to the peacock and also to the raven. It is merely a conjecture, but the great rarity of the printed book may be partly owing to these attacks on the priests. These allusions would naturally arouse the hostility of the very powerful theological bodies and, not unlikely, lead to attempts to suppress the book. In looking over the *Index librorum prohibitorum,* however, I have not found the *Book of Nature* on the list.

The illustrations in Conrad's *Book of Nature* are on twelve folio plates, inserted as leaves separate from the text, one plate at the beginning of each division of the book. The woodcutting is coarse, and the drawings are by no means so good as those of the *Gart*. So far as known these sketches have no forerunners; they are not traditional figures copied from earlier manuscripts, as was frequently the case of illustrations printed before 1530.

[14] For a translation of the account of the lion, as an example of the general tone of the writing, see the writer's article on " The Earliest Printed Illustrations of Natural History " in the *Scientific Monthly,* Sept., 1921.

On ten of the twelve plates there are not less than eighty-six figures of animals (some of the smaller repetitions not being counted). The remaining two plates contain nineteen figures of plants and trees.

The illustrations vary in quality — when the figures are of domestic animals, so that the designer could see examples, the

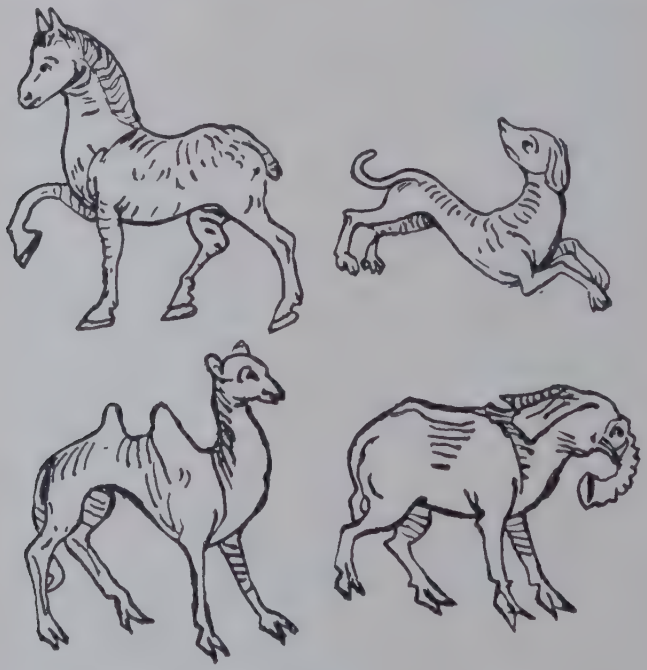

FIG. 14. — TRACING OF FOUR FIGURES FROM A FOLIO PLATE OF TWELVE QUADRUPEDS. (*Buch der Natur*, 1475, Pierpont Morgan Library.)

figures are rather good — see the dog and the horse in Fig. 14. The goose, dear to the heart of the German for festive occasions, the falcon (Fig. 15), the woodpecker, the peacock, although crude, are evidently drawn from nature. The exotic animals, however, such as the camel, the lion, and, especially, the elephant (Fig.

14), with cleft hoof and schematic trunk, are very bad — the designer had no specimens to draw from. The fishes, too, are not well drawn. The general appearance of the plates with their rough borders is shown in Figs. 16, and 17. Figure 16 shows several insects, ants, bees, grasshoppers, butterfly; a spider, a snail, etc. Figure 17 shows the grape vine, the apple tree, the pear tree, and other pictures less easily recognizable.

FIG. 15. — TRACING OF THE FALCON, FROM A PLATE OF THIRTEEN BIRDS. (From the same book.)

The rarity of Conrad's book, and especially of perfect copies, accounts for the little notice it has received and also for misconceptions regarding the number of plates which it contains. Mrs. Arber in her very fully illustrated treatise on "Herbals" reproduces one of the plates from the *Buch der Natur* (1475), and speaks of it as "The single plant figure with which the book is illustrated." Hugh William Davis, in his "Early Printed German Books," has already pointed out that five plates are missing from the copy of the first edition in the British Museum. For the second plate of botanical figures see Figure 17.

The introduction of pictures into printed books of science was an important step. The preparation of cuts forced observation and sharpened it. Through this means attention was directed to details and observation was promoted. This was an entering wedge of independent observation at a time when observation was struggling for the right to exist. The preparation of the figures required greater accuracy and some independent observation, and these original efforts were allowed to stand. They did not provoke the hostility of the censors as did original comments. The pictures might pass, but expressions of independent opinion might be contrary to theological doctrine. The

pictures in the *Garten der Gesundheit* were so much more notable that further comment will be withheld until the next section.

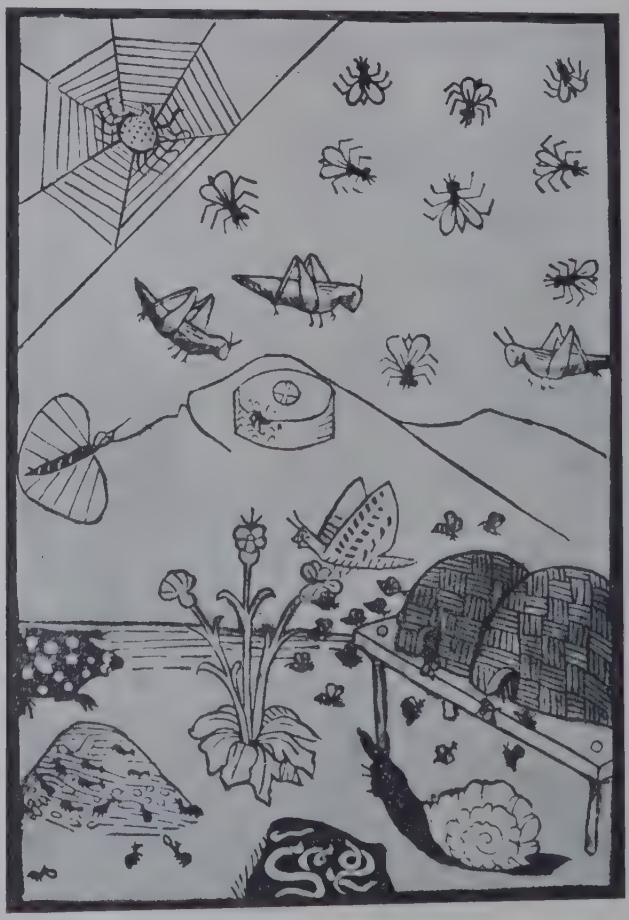

FIG. 16. — PHOTOGRAPH OF A FOLIO PLATE OF INVERTEBRATES FROM THE SAME BOOK.

For local color it will be interesting to compare figures of animals in contemporary books of different purpose, such as

Breidenbach's travels (1486); Bidpai, *Buch der Weisheit* (1486); the *Dialogus creaturarum* (1480); Bartholomæus Anglicus, Dutch edition (1486) and English (1495); the former with

FIG. 17. — PHOTOGRAPH OF ONE OF THE TWO BOTANICAL PLATES FROM THE SAME BOOK.

good pictures of animals and plants, the latter with wretched ones. The single plate of animal pictures in Breidenbach's

travels (Fig. 18) contains pictures that are superior as to drawing and as to woodcutting. Although there are some mythical animals represented, the camel and the giraffe are well executed

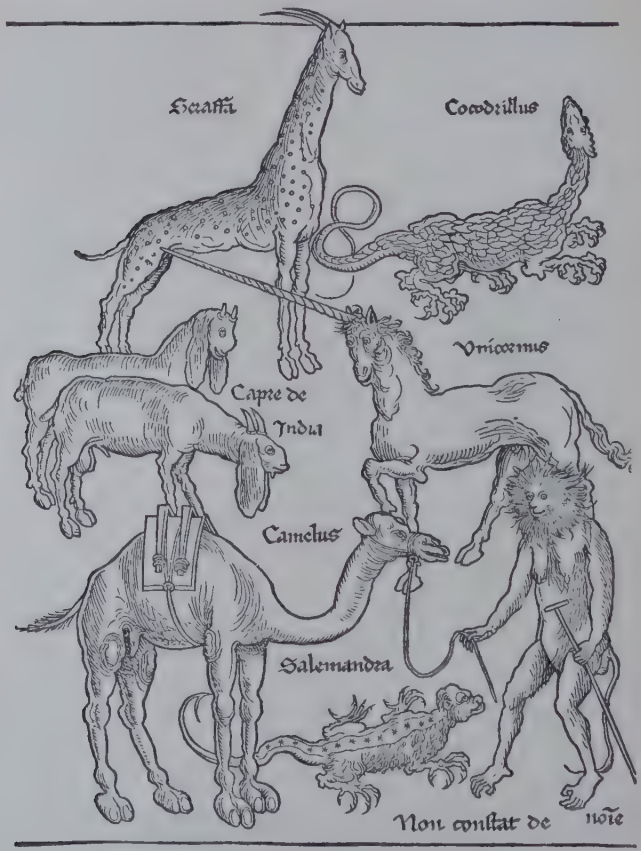

FIG. 18. — PHOTOGRAPH OF A FOLIO PLATE OF ANIMAL FIGURES. (Breidenbach's Travels, 1486, Pierpont Morgan Library.)

and are evidently drawn from nature. William Morris says, in general, of the many pictures in Breidenbach's book: "These woodcuts are remarkable, not only as the best executed illustrations in any mediæval book, but as being the first woodcuts

in which shading is used in masses and not merely to help the outline." In Bidpai (*Buch der Weisheit*, and other titles) is a grotesque figure of an elephant with cleft hoofs and a long, bovine tail, and, also, a schematic trunk similar to the one in Conrad's picture (Fig. 14). In the *Dialogus creaturarum* (1480) there occurs an elephant with the soliped hoof of the horse and

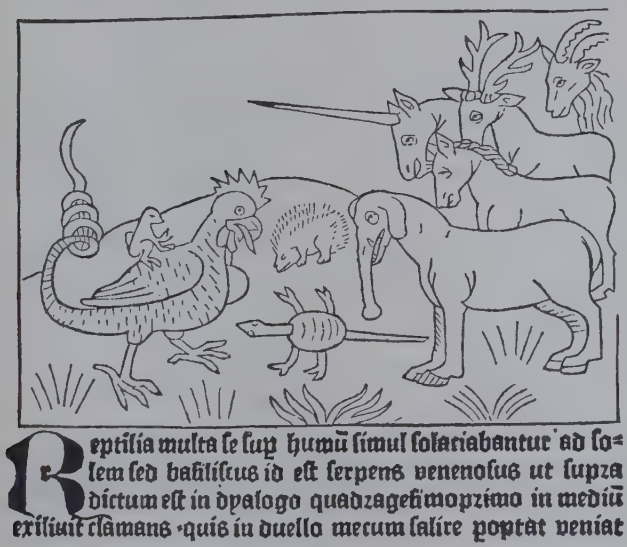
Reptilia multa se cum humū simul solaciabantur ad so=
lem sed basiliscus id est serpens venenosus ut supra
dictum est in dyalogo quadragesimoprimo in mediū
exiliuit clāmans quis in duello mecum salire poptat veniat

FIG. 19. — ANIMAL PICTURES FROM THE DIOLOGUS CREATURARUM, 1480. (Pierpont Morgan Library.)

with a horse's tail (Fig. 19). Now these are not pictures drawn for a scientific book, but, as representing the conception of these animals by designers of the time, they are significant. The figures in the Dutch edition of Bartholomæus Anglicus, although published in 1486, far surpass those of the English translation, published in 1495 by Wynkyn De Worde. The plate of quadrupeds (Fig. 20), of birds and of plants of the Dutch edition shows signs of observation from nature (compare the sketches of the elephant in the various cuts). The figures in the English

edition, on the other hand, are wretched caricatures — some of them being degraded copies of the figures of Conrad's book. Mrs. Arber publishes the botanical plate from the English edi-

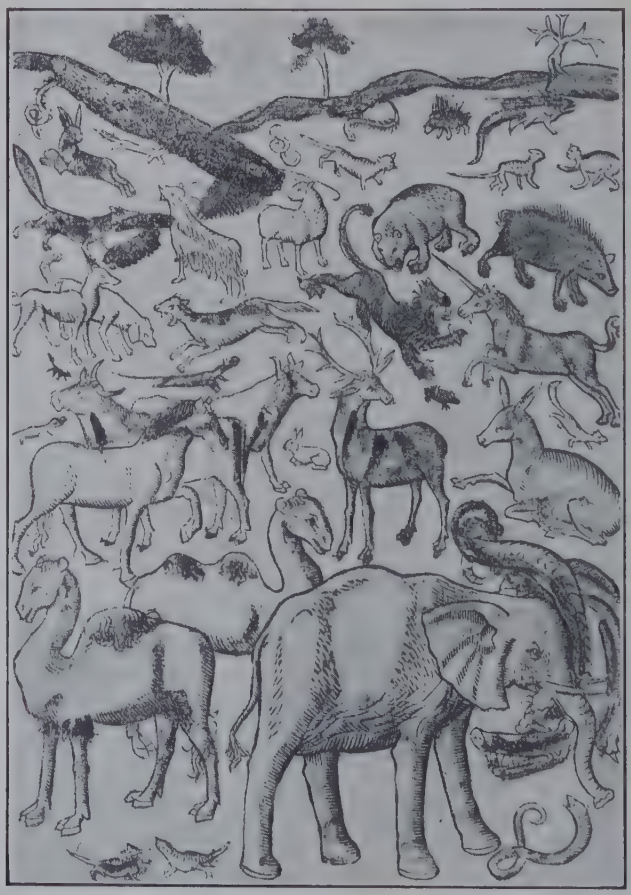

FIG. 20. — PHOTOGRAPH OF A FOLIO PLATE OF ANIMALS. (Bartholomæus Anglicus, 1486, Pierpont Morgan Library.)

tion of 1495, but the plant illustrations in the earlier Dutch edition are much superior.

THE *GARTEN DER GESUNDHEIT*

While the *Book of Nature* had a long history in manuscript, the German translation going back to 1349, the *Gart,* although a compilation, seems to have been a product of the time and to have been the expression of the publisher's enterprise — the excerpts being chiefly made by a physician acting as scientific collaborator, and the blocks being cut under the eye of the publisher. No anticipations of the illustrations nor of the text are known — except that the text is pieced together out of earlier writings on nature. From the preface it would appear to have been the product of the combined labors of the publisher, a Master of Medicine, and a skilful artist.

The following quotation is taken from Mrs. Arber's translation of the preface: "Since, then, man can have no greater nor nobler treasure on earth than bodily health, I came to the conclusion that I could not perform any more honorable, useful or holy work or labor than to compile a book in which should be contained the virtue and nature of many herbs and other created things, together with their true colors and form, for the help of all the world and the common good. Thereupon I caused this praiseworthy work to be begun by a Master learned in physic, who, at my request, gathered into a book the virtue and nature of many herbs out of the acknowledged masters of physic. . . . But when, in the process of the work, I turned to the drawing and depicting of the herbs, I marked that there are many precious herbs which do not grow here in these German lands, so that I could not draw them with their true colors and form, except from hearsay. Therefore, I left unfinished the work which I had begun, and laid aside my pen, until such time as I had received grace and dispensation to visit the Holy Sepulcre, and also Mount Sinai. . . . Then, in order that the noble work I had begun and left incomplete should not come to nought, and also that my journey should benefit not my soul alone, but the whole world, I took with me a painter ready of wit, and cunning

and subtle of hand. And so we journeyed from Germany. . . . In wandering through these kingdoms and lands, I diligently sought after the herbs there, and had them depicted and drawn with their true color and form. And after I had by God's grace, returned to Germany and home, the great love which I bore this work impelled me to finish it, and now, with the help of God, it is accomplished. And this book is called in Latin, *Ortus sanitatis,* and in German, *Gart d'gesuntheyt."*

Considerable obscurity has arisen as to the distinctive title by which this work should be known. Choulant, who in 1857 gave the first complete analysis of the book, called it the " smaller Hortus " and thus, although an independent work, it came to be confused with the " larger," or true, *Hortus sanitatis* which was first published in Mainz in 1491 and became widely distributed in later editions. Although the *Hortus sanitatis* owes something to the *Gart* as a forerunner of the same type, it differs in language and in extent — being much more voluminous and having 1066 figures, while the *Gart* originally had a total of only three hundred ninety-seven. Most of the pictures in the *Gart* were copied and recut for the *Hortus sanitatis,* but are of much lower quality. The *Gart* was originally prepared in German; the *Hortus sanitatis* was in Latin, but was not a translation of the *Gart,* although modeled after it and showing generic resemblances to it. Neither was the *Gart* a German translation of the Latin *Herbarius* which preceded it by one year (1484). The text and, notably, the illustrations are different, not only more numerous (one hundred fifty in the *Herbarius* and three hundred ninety-seven in the *Gart*) but of superior quality.

The extant copies are rarely complete and the title page is frequently missing; but, whatever the title on the fly leaf of the various issues and variants of the *Gart — Herbarius zu teutsch, Ortus,* etc., there occurs an unvarying title in every preface — " And this book is called in Latin *Ortus sanitatis,* in German *ein gart der gesuntheit."* [15] Arnold Klebs in his Incunabula Lists (1917) has greatly clarified the matter by a complete

[15] From the first Mainz edition, 1485.

analysis of what he calls the Hortus family, showing the family to consist of some forty issues of related books — the *Hortus sanitatis* of 1491 being the central member and the most extensive. The original edition of the *Gart* is the most important for determining the quality of its illustrations and any confusion of title should by all means be avoided. The suggestion of both Sudhoff and Klebs to designate the work by the short title *Gart* is opportune since this gives a distinctive title that cannot be confused with that of any other member of the Hortus family. The *Gart* is the original of the entire Hortus family. The name of the designer of the book is not known but the scientific collaborator is believed to have been Johann de Cube [16] and identified by Sudhoff with Johann de Wonnecké, a practicing physician of Frankfurt at the end of the fifteenth century.

A complete copy of the *Gart* of 1485 should contain three hundred fifty-six folio leaves, four hundred thirty-five numbered chapters with three hundred eighty-six pictures of plants (one repeated) and eleven of animals (one repeated).[17] Choulant mentions thirteen issues of the *Gart*. The number of illustrations varies in the different issues — one edition, with the addition of genre pictures, has as many as five hundred forty-two pictures.[18]

It is for its illustrations that the *Gart* is especially notable. The pictures are chiefly those of plants, numbering three hundred eighty-six, while there are only eleven pictures of animals. The pictures vary in quality, but seven pictures of animals and five or six of plants are of unique perfection among the early printed illustrations. The picture of the yellow flag (Acorus) (Fig. 21), of the white lily (Fig. 22) and of the fox (Fig. 23) are fine examples of drawings from nature. The cut of the yellow flag has

[16] Mentioned on page 127 near the end of chapter 76.

[17] The copy placed at my disposal at the Surgeon General's Library of Washington has three hundred twenty leaves, four hundred twenty-seven chapters, but lacks a few intervening leaves. I am greatly indebted to Colonel Garrison and others of the library staff for assistance and opportunity to photograph the plates of the book.

[18] Klebs, Incunabula Lists.

been published full-size by Dr. Payne and by Mrs. Arber, but, so far as I am aware, the figures of the white lily, of the fox, and of other animals have not been reproduced.

Fig. 21. — The Yellow Flag. (Garten der Gesundheit, 1485, Surgeon General's Library.)

No one can examine the original cuts and retain any doubt that they were drawn from nature by a skilful artist and a careful observer. The lines of the woodcuts are coarse but the few best

sketches rival those published by Brunfels (1530) and Fuchs (1542). The best [19] figures in the *Gart* show the highest level

FIG. 22. — THE WHITE LILY: FROM THE SAME BOOK.

to which botanical and zoölogical illustrations attained not only in the fifteenth but also in the first third of the sixteenth century.

[19] All the pictures in the *Gart* are not good, but seven or eight of them are of high quality and faithful copies from nature.

Forty-five years before the renovation of botanical illustration by Brunfels, and fifty-seven years before the publication of the figures of Fuchs, the best pictures of the *Gart* stand out as beacon lights in the development of scientific illustration. They are of singular importance in the history of scientific iconography and are deserving of great praise. An unprejudiced examination of them cannot fail to modify the incorrect estimate as to the quality of all printed illustrations of natural history before those of Brunfels.

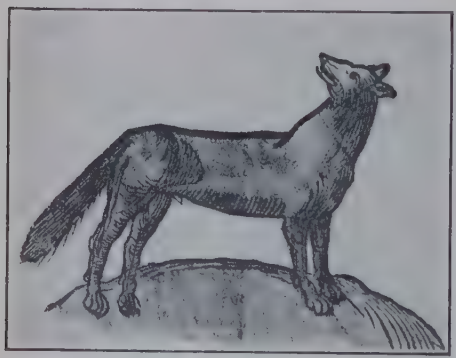

Fig. 23. — The Fox: From the Same Book.

In the botanical books that followed for forty-five years, from the printing presses of various countries, the pictures of the *Gart* were copied and recopied, but in the process they were degraded and conventionalized so that one can get a correct impression as to quality only by examining those of the first Mainz edition. Even so careful and original a student as E. L. Greene, whose *Landmarks of Botanical History* shows great thoroughness, maturity of judgment and first-hand acquaintance with the sources, repeats the generally accepted opinion, saying:[20] "To a generation that had been accustomed to such books as the *Hortus sanitatis*, filled with the most wretched caricatures of plants in place of true representations of them, this great book of Fuchsius must have appeared as nothing less than luxurious"; and again:[21] "Even forty or fifty years before these fathers of plant iconography there were printed copies of the *Hortus sanitatis*, and its German version, *Gart der Gesundheit*, illustrated by some five hun-

[20] Greene, *Landmarks of Botanical History*, p. 195.
[21] Page 167.

dred wood engravings of plants. Doubtless the wretched character of these first printed plant pictures, along with the great popularity of the books containing them, were what moved Brunfels to undertake the publication of the *Herbarum vivæ eicones*." Here a direct reference is made to the *Gart der Gesundheit* (the *Hortus sanitatis* having 1066 figures, instead of five hundred). The criticism will apply to the degraded pictures of the *Hortus sanitatis* [22] but not to the better pictures of the *Gart*. The explanation of such an unwarranted sweeping conclusion is doubtless to be set down to the great rarity of the *Gart*, and to the belief that, since the *Gart* was an earlier publication of the same type, the pictures of the *Hortus sanitatis* can be taken as showing the quality of the pictures.

No one can look at the pictures of the dodder, the yellow flag, the white lily, the fox, etc., in the original edition of the *Gart*, and consider them as wretched caricatures; they rival the printed pictures in the herbals of Brunfels and of Fuchs as to quality and fidelity to nature.

[22] The *Hortus sanitatis* is widely distributed in printed form; there are not less than thirty-four copies in American and a larger number in European libraries. Choulant lists thirty-three issues of the work; it is so easily accessible that the writer has had some fifteen copies for examination.

CHAPTER VIII

THE HERBALS OF THE SIXTEENTH CENTURY

The first half of the sixteenth century is a important period in the history of science as containing a renewal of observation of nature and the beginning of exact description. The improvement first appeared in botany. Though, therefore, through the publication in 1543 of Vesalius' great book on the structure of the human body, this period saw the final overthrow of dependence on authority and the beginning of a new epoch in natural science, we must give our attention first to the illustrated herbals of Brunfels (1530) and Fuchs (1542) and to the plant descriptions of Bock and Valerius Cordus which presaged this event.

We have seen that the disposition to make sketches from nature had been growing for a long time before Brunfels and Fuchs encouraged and made use of it in their printed books. Charles Singer, who has investigated the manuscript sources of plant pictures, says, "The early printed herbals . . . present a stage of development that can be paralleled in the manuscripts and it is thus perhaps unfortunate that the historians of botany have elected to begin their accounts with these printed books." [1] "Botany is perhaps alone among the sciences in that it is possible to tell its history as an almost continuous tale, and the invention of printing introduced no especially new element into that tale. . . . A close study of some of these beautiful (manuscript) works shows that the early printed herbals had predecessors, and that already in the thirteenth century the older merely stylistic method of plant illustration was giving way to a real attempt to represent nature."

[1] *Studies in the History and Method of Science*, Vol. 2, 1921, p. 78.

It is to be said, however, that the books of Brunfels and Fuchs of 1530 and 1542 made good illustrations widespread and easily accessible — which had scarcely been accomplished by the manuscripts. The particular service of Brunfels and Fuchs was to supply good pictures of plants through the medium of printed woodcuts. These pictures were drawn from nature, but Brunfels and Fuchs did not, as Sachs implies, " go straight to nature " for their descriptions. The descriptive part of their herbals was chiefly compiled, or even verbally copied, from the works of earlier writers, such as Theophrastus, Dioscorides, Pliny and others. Bock and Cordus, on the other hand, did something else. On the basis of their own observations they described plants with accuracy, clearness and system. Lee Greene has pointed out " that in the Germany of the first half of the sixteenth century, there were two fathers of plant iconography and two fathers of descriptive botany."

The term " Herbal " used in reference to books of the fifteenth and sixteenth centuries is not always restricted to books about plants; it is generally applied in a broad sense to nature-books which deal with animals, plants, minerals, and more or less with domestic medicine. The *Book of Nature* of Conrad von Megenberg treats more extensively of animals than of plants, but is, nevertheless, reckoned among the Herbals. Even the *Materia medica* of Dioscorides, although predominantly botanical, has sections dealing with the medical properties of animals and minerals. The existing manuscript herbals constitute a long series covering a period of nearly a thousand years, and leading up to the printed examples. But it happens that the books now under consideration are herbals in the restricted sense of dealing only with plants.

BRUNFELS' HERBAL

The title of Brunfels' folio volume, " Living Pictures of Herbs," (*Herbarum vivæ eicones*), conveys an idea of the nature of the book. Its pictures freshly made from nature are its most notable feature. These, to the number of about three

hundred, are for the most part very carefully executed. The book, published in three parts in Strassburg, 1530–1536, went through several editions and was translated into German in 1532–1537.[2]

The author, Otto Brunfels (Otho Brunfelsius) (1464–1534), received a university education and for the greater part of his life was a theologian; it was only late in life that he became a schoolmaster, a physician and a writer on botany. He was sixty-five years of age when he took his medical degree at Basle, and he served only a year and a half as City Physician of Berne up to his death in 1534. Originally a Catholic and a brother in a Carthusian monastery, in his native town of Mayence, he became attracted to the Protestant movement, and about 1517, when he was 53, he left the monastery and soon became a Lutheran pastor. After his voice weakened so that he could no longer preach, he established a boy's school at Strassburg.

FIG. 24. — OTTO BRUNFELS, 1464–1534. (Van Kaathoven collection, Surgeon General's Library.)

His activity as a theological writer, and author of pamphlets in support of the Lutheran movement, is attested by the large number of known titles of his productions. The revenue derived from the sale of his theological writings and from his school enabled him to employ good artists to illustrate his botany. His other writings are now forgotten and his name is perpetuated only by the work occupying a few years of his old age. Lee Greene points out that he influenced botany in another way

[2] The Latin copy which I have used in the John Crerar Library of Chicago is dated 1532 and embraces parts one and two; part three (1536) which is rare I have not seen.

— when he was sixty-nine years old, he journeyed on foot from Strassburg to Hornbach, a distance of fifty miles, to visit a younger and less affluent botanist — Bock — and it was owing to the encouragement of Brunfels that Bock wrote his herbal.

Fig. 25. — Plantago. Reduced. (Brunfels, Herbarum vivæ eicones, 1530, John Crerar Library.)

Brunfels did not pretend to have advanced the art of plant description; as he says in his dedicatory epistle, his descriptions were "extracted from accurate and trustworthy authors" — as to his personal contribution he lays claim only "to new and really life-like engravings." The plants represented were those growing in Germany; as he had no notion of geographical distribution, the figures and the descriptions often fail to correspond. Frequently also he took his descriptions, not directly from the original sources, but from commentaries by Italian scholars. Brunfels held Theophrastus in the highest esteem, and he cites Pliny, Dioscorides, Avicenna, Rhazes, and the host of other mediæval writers on botany.

Two pictures, Plantago and Lily of the Valley (Figs. 25 and 26) will give some idea of Brunfels' illustrations, but they are so much reduced that they scarcely convey an adequate impression of the beauty of the originals.

It is safe to say that Brunfels' work is chiefly valuable for

its pictures. Miall ascribes to him a more commanding position in botany, saying that "by figuring plants from nature Brunfels initiated modern systematic botany." But the credit for reforming descriptive botany belongs rather to Valerius Cordus, and, in a less degree, to Bock, while Brunfels should be designated as a plant iconographer. Even as an illustrator of plants, he was "not an isolated manifestation" of his period. He was preceded by wonderfully accurate plant drawings by Albrecht Dürer (1526) and by Leonardo da Vinci as well as by the series of manuscript drawings already mentioned.

FIG. 26. — LILY OF THE VALLEY: FROM THE SAME BOOK.

Brunfels' changes and improvements in phraseology constitute a long and complicated story, into which Lee Greene has gone, and the botanical reader must be referred in this matter to Greene's *Landmarks of Botanical History*. Some summary statements, however, may be made. Brunfels deals more with wild than with cultivated plants. He wrote for apothecaries and physicians, giving attention to medical qualities. To a considerable extent, he abandoned the purely alphabetical arrangement common in the mediæval nature-books, and made some groups based on morphological likeness and similarity of medical properties. It should be kept in mind that Brunfels was a well-educated man trained in making careful distinctions, and when he took up botany and medicine he was already advanced in age and experience, with a record as a writer of theological works. Although his text is derived from earlier writers, from time to time

he introduces some ideas of his own. The time had not arrived when flowers were made use of in determining the position of plants. He made use of root, stem, leaves, and seeds. On the basis of morphological observation he also introduced some improvements in the naming of plants. At the same time he did not make extensive changes. As Greene remarks: "Brunfels was not of the temperament of the taxonomic revolutionist but only a (conservative) reformer. Moreover, he kept in mind that he wrote for the sellers of drugs who were impatient of changing the commercial names of their commodities."

He hesitated to invent new Latin names for undescribed plants which he found from time to time. He figures and makes known for the first time the wood anemone, the white clover, and other plants, but instead of inventing a Latin name for each of these he gives the common German name by which they were known to the peasantry. "Brunfels gave no thought" to the nomenclature of species. That concept was introduced into botany at a much later date. The common white clover, *Trifolium repens,* known to the common people by the name of *Weiss Fleischbluem* bears no other designation in Brunfels' Herbal.

Mrs. Arber lists fourteen separate titles of printed herbals, most of them with illustrations, which preceded that of Brunfels. It will be much too detailed for our purpose to attempt to give an account of these books in addition to what is said of some of them in Chapter VII.[3]

LEONARD FUCHS

The production by Fuchs (Leonhardus Fuchsius, 1501–1566) of a more extensive herbal was probably inspired by the suc-

[3] The particular one to which I owe a feeling of admiration, on account of the artistic (rather than naturalistic) quality of the illustrations, was published in Venice in 1499 under the title *De virtutibus herbarum.* The fine quarto copy in the Surgeon General's Library at Washington has one hundred forty woodcuts, and the authorship is (erroneously) ascribed to Arnold de Villa Nova. The book is a somewhat modified edition of the *Herbarum moguntinus,* 1484. I have examined two copies of this *Herbarum,* one in the John Crerar Library in

cess of that of Brunfels. The author was a university professor and a practicing physician. Like Brunfels he was brought up a Catholic, but came under the influence of the Lutheran movement which he espoused with great energy. After graduation in medicine from the University of Ingolstadt, at the age of twenty-three, he practiced for two years in Munich and then became a lecturer on medicine at Ingolstadt. Here, however, he was subjected to discomfort if not persecution on account of his Protestant activities, and after a few vicissitudes, went to the newly established (Protestant) university of Tübingen where he remained for the rest of his life. He was an important teacher and was twice elected rector of the university. He enjoyed also an extensive practice of medicine. The duties of his professorship and his extensive practice occupied his energies so fully that it is assumed that he engaged in botanical studies as a sort of recreation. Be that as it may, he was convinced of the value of botanical studies for the student of medicine. In 1539, he wrote into the statutes of the university a plan of medical studies which included observations in the field and a practical familiarity with plants. "During the summer months," says Fuchsius, "the student of medicine should often go to the country and to the mountains, and with intelligence collect and study plants; this study should become a part of the curriculum of medical studies.[4] But in his own case, his warm words of appreciation show that he did not study botany merely for its utility. In the preface of his herbal we find these words: "There is nothing in this life pleasanter and more delightful than to wander over woods, mountains, plains, garlanded and adorned with flowerlets and plants of various sorts. . . . But it increases that pleasure and delight not a little, if there be added an acquaintance with the virtues and powers of these same plants."

The Herbal of Fuchs (*De historia stirpium commentarii in-*

Chicago and one at the Pierpont Morgan Library in New York, but the original Latin edition of 1484 with its one hundred fifty pictures of plants, conveys no feeling of inspiration; the figures are rude and the text formal.

[4] Haec itaque docendi ratio posthac in scholis medicis obseruator — Neumann.

signes, etc.) published in Latin at Basle in 1542, and in German the following year, has five hundred fifteen woodcuts of plants, each occupying a folio page.[5] They were beautifully executed from nature and drawn in outline without shading. This was to allow of coloring by hand or with a stencil. Neither of the two editions in the John Crerar Library has the illustrations colored, the copy belonging to Northwestern University has all the pictures colored by hand. In the later edition the names on the plates are in Latin and in German, but in the German edition the Latin names are omitted. In the German edition the long, dedicatory epistle is omitted and also the explanations of botanical terms. The same plates are used for the cuts, but the Latin name is omitted and in some cases the text is abbreviated. As the book was intended for the people in general, the Latin names were omitted from the plates. In the three hundred forty-three chapters, each dealing with a genus, the book contains descriptions of approximately four hundred plants native to Germany and about one hundred foreign plants. Among the exotic plants are the first known pictures of two from North America — the pumpkin and Indian corn.

FIG. 27. — LEONHARD FUCHS, 1501–1566. (Frontispiece, folio size, Historia stirpium, 1542, John Crerar Library.)

The frontispiece is a standing portrait of Fuchs in his forty-first year (Fig. 27), and at the close there are three woodcuts

[5] There is a fine copy of this edition in the John Crerar Library, Chicago; also an illuminated copy in Northwestern University Library.

representing his three draftsmen and the wood engraver. Writing of the illustrations, Fuchs himself says, each " is positively delineated according to the features and likeness of the living plant, we have taken particular care that they should be most perfect and . . . that every plant should be depicted with its own roots, stalks, leaves, flowers, seeds and fruits." [6] He also praises the skill of his artists and of " Vitus Rudolphus Specklin, by far the best engraver of Strassburg." The book became very popular; it was at once translated into German, and it was reproduced in many different forms, some of the issues being small and inexpensive.

The pictures are in much greater number than those of Brunfels and on the whole they arouse a higher degree of admiration. I believe with Mrs. Arber that the illustrations of Fuchs " represent the high-water mark of that type of botanical drawing which seeks to express the individual character and habit of each species, treating the plant broadly as a whole, and not laying more stress upon the reproductive than the vegetative organs."

The long and rather boastful title [7] may be rendered into English, as " Renowned commentaries on the history of plant-stocks, elaborated with the greatest effort and diligence, more than five hundred living pictures of these having been added, never before represented more skilfully to the likeness of nature, by Dr. Leonard Fuchsius, by far the most celebrated author of our time." In defence of Fuchs, however, it should be said that the title was probably introduced by the publishers.

The lives of Brunfels and Fuchs afford a contrast. Brunfels was most of his life a theologian, and incidentally a botanist and medical man towards the close of his career. Fuchs, on the other hand, was a life-long scientific man, distinguished as a teacher of medicine, a practitioner and a writer on medical sub-

[6] Arber's Herbals.

[7] De historia stirpium commentarii insignes, maximis impensis et vigiliis elaborati, adjectis earundem vivis plusquam quingentis imaginibus nunquam antea ad naturae imitationem artificiciosius effictis et expressis, Leonarto Fuchsio medico hac nostra aetate longe clarissimo auctor etc. Basileae in officina Isingriniana. 1542 in fol. maj.

jects. Being, like Brunfels, a scholar, he made use of earlier writings in the original tongues. He published a larger number of figures than Brunfels, but his text is briefer, and, according to Greene, less scholarly. His scientific contributions include medicine and were much greater than those of Brunfels; nevertheless, he never rose very high as a botanist and he is to be looked on, like Brunfels, as a plant illustrator rather than as one who advanced plant description or scientific botany. In fact, he was merely a medical botanist, dealing with plants from a utilitarian point of view, and providing illustrations for the more certain identification of plants sold by pharmacists and used by physicians in their practice.

The income from his practice and his professorship provided the means with which he kept draftsmen and wood engravers at work, and after the publication of his *De historia stirpium,* he continued to accumulate pictures until they reached the very large number of fifteen hundred. Towards the end of his life he proposed to publish an illustrated work of monumental size on plants, and to include in it the fifteen hundred cuts which he had assembled. The expense of the enterprise, however, was staggering. He was not able to find a publisher, and was unwilling to bear the expense himself, so that he passed away without realizing this larger enterprise. After his death the plates were scattered and some of them were used to illustrate other treatises.

Herbals dealing exclusively with plants appeared in considerable number both before and after 1530, the date of publication of the first part of Brunfels' *Eicones*. In addition to those mentioned in Chapter VII, we have *Le Grand Herbier* of France, and its English translation published in 1526 under the title " The grete herball." In the Netherlands [8] there appeared

[8] In connection with the printing of illustrated herbals in the Netherlands mention should be made of the famous printing house of the Plantin family at Antwerp, publishers in the very front rank of the art of printing for a period of eight generations. Through the marriage of one of Plantin's daughters to Jean Moretus, the business was conducted by their descendants to the year 1876, when the citizens of Antwerp purchased from the last of the line the *Maison Plantin* and its contents. This is now preserved as a museum (*Musée*

illustrated botanical works by Dodoens, by Charles de l'Écluse and by Mathias de l'Obel. The wood-blocks of pictures were largely borrowed from Fuchs' *De historia stirpium* and from other illustrated herbals. In the case of de l'Écluse, however, the wood-blocks were especially engraved for his works.

In Italy, in 1544, appeared the famous commentaries on Dioscorides by Matthiolus, and, in 1592, the treatise of the lawyer-botanist, Fabio Colonna. The work of Colonna is notable for good descriptions and for its pictures — the latter being the first etchings on copper used to illustrate a botanical work.

In Switzerland, botany was advanced notably by Konrad Gesner and Kasper Bauhin whose works are so important that they will be taken under consideration later.

In France, Ruel (Ruellius) and d'Aléchamps are outstanding names, the first producing *De natura stirpium,* in 1536, and the second *Historia plantarum,* etc., in 1586, illustrated with twenty-seven hundred figures.

In Germany, outside those especially considered in this chapter, perhaps the chief name is that of Camerarius whose *Hortus medicus et philosophicus* (1588) has figures taken partly from Gesner and partly original which "represent a considerable advance, since the details of floral structure are often shown on an enlarged scale."

In England, William Turner, "Father of British Botany," was publishing a work giving the habitat of English plants, and, in 1551–1568, there appeared his "Herball," the chief botanical treatise in England of the Elizabethan period. In 1597, John Gerard, "best known of English herbalists," published *The Herball or Generall Historie of Plantes,* illustrated with many woodcuts.[9]

All this makes too long a story to follow in detail.

Plantin-Moretus) and is visited and much admired by travelers to Antwerp. Mrs. Arber says, "In short, the Maison Plantin beggars description, and a visit there is an infallible recipe for transporting the imagination back to the time of the Renaissance, when printing was in its first youth, and was treated with the reverence due to one of the fine arts."

[9] An improved and corrected edition of Gerard's Herbal was prepared by

PLANT DESCRIBERS

We come now to treat of two men who described plants from their own observations, and on that account stand out in contrast with their contemporaries, Brunfels and Fuchs, who merely provided illustrations of plants and took their descriptions from others. These men were Bock and Valerius Cordus.

Hieronymus Bock (1498–1554), generally known under the Latin form of his name as Tragus, was "singularly gifted as a botanist." He was born at Heidesbach, not very far from Heidelberg, of pious parents who wished to devote him to monastic life, but, as he grew up, the ecclesiastical revolution of Luther was in progress and Bock forsook the doctrines of the established Catholic church to join the Protestant movement.

FIG. 28. — HIERONYMUS BOCK, 1498–1554: FROM AN OLD CHALK DRAWING. (Acta Horti Bergiani.)

Little is known regarding his early life; he shows signs of having received a good education, but where he received his training is uncertain. Because he practiced both theology and medicine, it is assumed that he had a university training in each, though no records are known to substantiate this. At twenty-five we find him married and under appointment at Zweibrücken as a schoolmaster and superintendent of the garden of the Palatinate Count Ludewig. Here he remained nine years until the death, in 1532, of Ludewig, his patron, and then lost his position because the successor of Ludewig was not friendly to Protestants. Soon thereafter, curiously enough, we find him receiving appointment to a richly endowed Catholic holding, the

William Johnson and printed in 1633, and again, unaltered, in 1636. A very beautiful copy of the latter printing is in the library of the University Club of Chicago.

church of St. Fabian, in the village of Hornbach, where he preached the gospel, engaged in medical practice and followed his natural bent for botanizing. (He made his botanical excursions in peasant dress to avoid attracting attention.) But he was soon forced to retire, owing to his outspoken Protestant principles, and found himself in great need.

In his extremity he was now rewarded for some of his past work. In grateful memory of having been cured by him of a serious illness, the Count Philip of Nassau provided him with shelter and free living. This enabled him to continue his botanical studies and writings until, after several years, he was called back to Hornbach, where he was joyfully received and remained to the close of his life in 1554. It is supposed that his reappointment at Hornbach was owing to the circumstance that the newly appointed Bishop was favorable to the Protestant movement.

Bock was a lifelong lover of plants in their natural surroundings and, partly at least, through the encouragement of Brunfels, for whose book he had supplied some notes, Bock undertook to provide a botany in the German tongue with such clear and accurate descriptions that pictures of the plants would not be necessary for their recognition. This he accomplished and in 1539 there appeared parts one and two of his *New Kreutterbuch*. This was followed by an edition in which the "New" was omitted and the title reduced to *Kreutterbuch*.

Originally, it was not intended to be illustrated but, to meet the competition of trade, the publisher wished to insert figures in a new edition, and Bock agreed. In 1546, an illustrated edition of parts one and two was published along with part three. The book was translated into Latin; but it was in the German editions that it became popular and widely circulated. Finally, in some editions it came to have as many as five hundred thirty-seven pictures. The pictures, for the most part, were made by David Kandel, a young self-taught artist, some being original and others, reduced in size, were copied from Fuchs and other

authors.[10] Some of the editions contain the portrait of Bock drawn by David Kandel whose initials appear on the base of the columns enclosing the portrait. The introduction of pictures was a trade enterprise, and Bock is to be remembered not as iconographer but a plant describer.

Through his simple and homely language he reached the people. Says Miall, "Particulars of place and environment are added, and the descriptions are enlivened by curious details, which give them in many places a vivacity to which the text of Brunfels or Fuchs makes no approach."

As an example of his writing, I quote from Greene's "Landmarks"[11] Bock's description of the common mullein. This plant had been used in medicine from the time of Hippocrates; but scarcely more than a line of description, and that of the leaves only, had been given by the earlier writers. Bock had, therefore, no model to copy. He writes of the mullein as follows: "A very notable thing in this plant is the long straight thick root, of a woody hardness. Its leaves, especially the earlier, lie close to the ground, are rather broad and long, of a whitish aspect and woolly, more so than those of helenium (*Inula helenium*). Not until the second year does it send up its stem, full of a white pith within, like the elder, and sometimes attaining a man's height, clothed with leaves which gradually become smaller and narrower as they approach the summit. The flowers, yellow, woolly, and most sweet smelling are of five distinct leaves, and completely cover the stem from where they begin up to the very apex of it; which falling away are succeeded each by a woolly globe crowded full of seeds not unlike those of a poppy. When the plant is in flower it resembles a beautiful torch, whence the name King's Torch has been given it." Space does not permit of giving further examples.

Valerius Cordus (1515–1544) was a keen and gifted observer with unusual powers of clear exposition; his plant descriptions are so lucid, so complete, so straightforward and systematic that we

[10] The edition of 1580, in the John Crerar Library, is provided with five hundred sixty-seven pictures which are small and coarse.

[11] Page 225.

must, I think, recognize him as the first masterly describer of modern science. Good as are the descriptions of Bock, those of Valerius Cordus are better; those of Bock are in a popular style, those of Cordus more thorough and scientific. Dying at the age of twenty-nine, he left descriptions of nearly five hundred plants, none of which, however, were printed until seventeen years after his death. Cordus received from his father a most careful training in languages, philosophy, and especially in scientific method; he was talented and developed early. His father (Euricus, a physician) himself has a name in botany, though he was far surpassed by his gifted son.

Fig. 29. — Valerius Cordus, 1515–1544. (Van Kaathoven collection, Surgeon General's Library.)

Valerius Cordus was born in 1515, at Siemershausen, in Hesse. Leaving the tutelage of his father, he attended the University of Wittenberg and received his Doctor's degree at the age of nineteen. In recognition of his attainments, the university at once accepted him as lecturer (Docent) to medical students on the *Materia medica* of Dioscorides. He made some improvements on Dioscorides and on the methods of preparing medicines. While staying with his uncle, an apothecary of Leipzig, as a pastime he prepared a Dispensary, not intended to be printed, but his uncle thought so highly of its usefulness that he secured its publication in 1535, and the *Dispensatorium*, the only work of Cordus published during his lifetime, had a wide circulation.

Botany was his passion; with uncontrolled zeal he threw himself into its pursuit, making field trips, collecting plants, and writing the results of his own observations. Having a desire to see in their native surroundings the plants of the Mediterranean region, described by the classical writers, he went to Italy in 1542 where he remained two years, chiefly at the universities of Padua,

Ferrara and Bologna. Here he met among others Luca Ghini, the most accomplished botanist of the time, "but of whom only the tradition has come down to us because he published nothing."

He traversed Italy to Rome, collecting and observing as he went. In the summer of 1544 Cordus, in his enthusiasm, ranged from mountains to swampy lowlands, collecting and observing with uncontrolled fervor. Thus he weakened his powers of resistance to disease. After receiving a painful kick from a horse, he fell ill with a fever and died in Rome at the age of twenty-nine.

Before going to Italy, Cordus already had in manuscript four books of a work which he entitled *Historia plantarum,* and in Italy he added a fifth part. The four parts, prepared by the time Cordus was twenty-five, contain four hundred forty-six chapters, each devoted to the description of a plant. In Italy he added the descriptions of twenty-five entirely new plants, but these were not published at the same time as his original four books. After his death the manuscript of the *Historia plantarum* came into the hands of the publisher Wendel Rihel, and was sent to Konrad Gesner, the eminent Swiss naturalist, to be criticized and edited. Gesner, a man of the highest scientific standards, spoke of the four books as "truly extraordinary because of the accuracy of the descriptions." He prepared the work for the press and published it at Strassburg in 1561, as *Historia stirpium,* in a single volume with annotations on Dioscorides, notes on plants, etc., all by Cordus, and some writings by several other hands. Pictures, largely from the wood blocks of Bock, were introduced at the insistence of the publisher. Some of these, of very mediocre quality, detracted from the excellence of the volume, as they drew the attention away from the beautifully clear text of Cordus which should have stood alone on its merits. The fifth part was published in 1563, together with his lectures on Dioscorides (*Annotationes ad Dioscoridem*) taken from the lecture notes of a student.

"The great merit of the *Historia* lies in the vividness of the descriptions." Cordus received recognition and high praise from

the most critical botanists of the seventeenth century such as Tournefort, Haller and Linnæus, It is to be regretted that Sachs disregarded the established opinion of this court of peers and passed by Valerius Cordus without any review of his work. E. L. Greene by a careful analysis (1909) of Cordus' *Historia stirpium* has placed him again in his true position as the greatest botanical describer of his period. Greene's statement, however, that Sachs speaks of Cordus as "unimportant" is scarcely justified. What Sachs writes[12] is: "We pass over Valerius Cordus, Conrad Gesner, Mattioli, and some other unimportant writers, etc." Evidently, what Sachs means is that he passes over Valerius Cordus, Gesner, etc., and some other (unmentioned) "unimportant" writers. He had already spoken of Gesner and had indicated that the publication of Gesner's work had been too long delayed (1751) to have direct influence on the progress of botany up to Linnæus.

Cordus thought out and strictly followed a definite plan or outline for describing plants. The main features of this plan are, according to Greene: First, there must be before him a living plant; the specimen must be mature, or at least in flower, the fruit to be waited for if necessary, and described later. He begins with the most obvious parts, the stem first, unless it be insignificant; if the foliage is most conspicuous, this comes first and the stem thereafter. The flower is taken next in order. Fruits and seeds are described with great precision. The root is always the last part of the plant to be described. With herbaceous plants he gives the natural duration as annual, biennial, or perennial. He makes the briefest possible mention of medical qualities, showing a purpose to distinguish in this work between descriptive and economic botany.

Cordus described in his own language not only new plants but "some of the best known and even best described plants of Dioscorides," and thus the young writer challenged comparison with the heralded master of *materia medica*. One example of the comparison, borrowed from Greene, must suffice: Dioscorides,[13]

[12] *History of Botany*, p. 29. [13] Book II, chapter 162.

— "*Arum,* called *Lupha* by the Syrians, sends up leaves like those of *Dracunculus,* but larger and less spotted; stem purplish, nine inches high, bearing something like a pestle, upon which the red seeds grow; root like that of *Dracunculus* white." Valerius Cordus,[14] — "*Arum* in early spring sends up its leaves each rolled together like a cloak and the roll slenderly pointed; these gradually expand and assume the outline of an ivy leaf, though they are much larger, sometimes attaining the length of nine inches, ending in a point, but widening below, yet receding into a sinus where joined to the petiole. In certain localities the leaves are purple spotted. At the same time of year it sends up another rolled up cloak which rests at the summit of a short upright stalk, and which about the middle of May opens to something like the form of a rabbit's or a donkey's ear, and shows within that which may be likened to the pestle of a mortar, is about the length of the little finger, erect, of a dull purple or ashy color, and rests on a kind of roughish tubercle, beneath which there is another tuberculation of the same size but paler as to color. This last-named tuberculation, after the one above it and the pestle have withered, grows to the size of a walnut and takes on the aspect of a bunch of red berries, each berry containing a seed or two a little smaller than a lentil. This thing ripens at about the summer solstice and the knot of shining berries and its stalk are all that remain visible of the plant at that time; and when these have fallen away everything disappears. The plant is from a bulbous perennial root of the size of the first joint of the thumb, white, delicate, which is found in a shrunken and withering state under the growing herb, yet after the withering of the herbage is found increased in size and firm. It sends out many eyes or tubercles by means of which the plant is propagated. Every part of the herbage exhales a heavy odor, and is so acrid in flavor as to affect the tongue and palate of him who tastes it as if he had swallowed thistles or briars. The plant inhabits shady places in deep woods, or old and shaded drains and ditches, or along hedges. Some cultivate it in gardens."

[14] Book I, chapter 50.

Cordus' description, although somewhat lengthy, is definite, and shows thorough observation throughout the life-period of the plant. The two descriptions differ in purpose; Dioscorides' purpose is medical, that of Cordus is to give a systematic description with enough data to enable a collector to recognize the plant.

How very different was the contribution of Cordus from that of Brunfels and Fuchs can be realized only by dwelling on his originality and the high quality of his descriptions He did something that Brunfels and Fuchs did not undertake. At the same time we should keep in mind that facility of description and influence on the progress of botany are not the same thing. Probably the work of other writers of the sixteenth century, such as de l'Écluse, de l'Obel and especially of Kaspar Bauhin, entered more directly into the current of progress. But even these men did not reach the goal towards which they were striving. The real progress of systematic botany was dependent upon the perception of natural relationships, and the fatal hindrance to arriving at any system of natural classification was the belief in the constancy of species — each kind separated from every other kind by being a special act of creation. Strive as men would for the discovery of a basis for a natural classification, by philosophical reasoning as in the case of Cesalpino, or by comparative observation as with Kaspar Bauhin, the goal was unattainable except through the study of life histories and the recognition of community of descent in plants. These advances were arrived at fully only in the last half of the nineteenth century.

SYSTEMATIC BOTANY FROM VALERIUS CORDUS TO JOHN RAY

We have seen from the foregoing account that botany took a new start in the early part of the sixteenth century, and with the basis already laid this is a convenient point to indicate in outline the history of botany from the systematic side, up to John Ray, the immediate predecessor of Linnæus. Confining the story to the narrowest limits, we mention only some of the greatest names, such as Gesner, Mattiolo, Kaspar Bauhin and Cesalpino.

Conrad Gesner (1516–1565) was a man of many interests, the most learned naturalist of the sixteenth century, so-called the "German Pliny," in early manhood a professor of Greek at Lausanne, and later professor of natural history and medicine at Zurich. Born in Zurich, the son of a poor furrier, like his father and so many of the scientific contemporaries, he became a "stout Protestant." Being of great promise he was aided by individual patrons, and by a "travelling stipend" awarded by his native city. He studied in Strassburg, Bourges, Paris, Basle, and other places. He was so fascinated by his opportunities in Paris that he engaged there in a course of extensive reading, doubtless to his own benefit but to the harm of his university studies. He married, imprudently, at an early age, and struggled along until he took his degree in medicine at Basle in 1541. During an epidemic of the plague, devotion to his professional duties as city physician of Zurich resulted in his taking the disease, and brought his life to a close in 1565.

Fig. 30. — Conrad Gesner, 1516–1565. (Historiæ animalium, liber III, qui est de avium natura, Zurich edition, 1555, John Crerar Library.)

His famous *Bibliotheca Universalis,* a compendium of all known writings in Latin, Greek and Hebrew, is a work of vast size and stupendous industry. Originally intended to occupy twenty-one volumes, he completed all except volume twenty, which was to deal with medicine and the natural sciences. He published a voluminous work on the history of animals (*Historia animalium*) which will be commented upon in a later chapter.

He was perhaps better fitted to write a book on plants than any other man of his time. His voluminous letters show his great

interest in this project, and tell of his many botanical excursions into the mountains as well as other regions. The ancients mention a single gentian; Gesner knew of ten or more. Harassed by many distractions and multifarious occupations thrust upon him, before his death, by monumental industry and powers of quick work he had nevertheless accumulated not less than fifteen hundred drawings to illustrate his projected work on the history of plants. He had intended this, his best-loved project, to be a companion work to his *Historia animalium*. We have no knowledge of Gesner's manuscript for the "History of Plants," but after many vicissitudes the pictures, sometimes used to illustrate the works of others, and finally reduced to the number of one thousand, were published at Nüremberg, in 1751–1772. The book *Opera Conradi Gesneri,* etc., contains all his botanical writings. It was edited by Schmiedel and is in two large folio volumes. Gesner, says Sachs, "was the only one who bestowed a closer attention on the flowers and parts of the fruit; he figured them repeatedly, and recognized their great value for the determination of affinity, as we learn from his expressions in his letters." Judging from the quality and the importance of his *Historia animalium* we are perhaps justified in presuming that had he lived to complete his botanical treatise and to see it published, it would have become the standard treatise on botany and have retained its preëminence at least until the appearance, in 1623, of Bauhin's *Pinax*.

Pierandrea Mattioli (1501–1577) finds a place here on account of his widely circulated Commentaries on Dioscorides. Born in Siena, he passed his youth in Venice where his father followed the practice of medicine. He began studies at Padua looking towards a legal career, but in order to indulge his natural taste for botany forsook the law and took up medicine. After graduation he practiced at Rome, in the bishopric of Trent, at Gortz, and at Prague, enjoying both ecclesiastical and royal favor and becoming rich and famous. At Prague he was knighted by the Emperor Ferdinand and was appointed by Emperor Maximilian II to be his personal physician.

Matthiolus (the Latin form of his name) gave most of his scientific life to elaborating in successive editions his *Commentarii, in sex libros, Pedacii Dioscoridis,* etc. His annotations were very extensive, embracing his own observations, and they made a new book of Dioscorides' *Materia medica.* The " Commentaries " became the standard text on Dioscorides and was one of the most widely read books on botany of the period; it passed through sixty editions, was translated into many languages, and it is recorded that of the first edition alone there were sold thirty-two thousand copies.

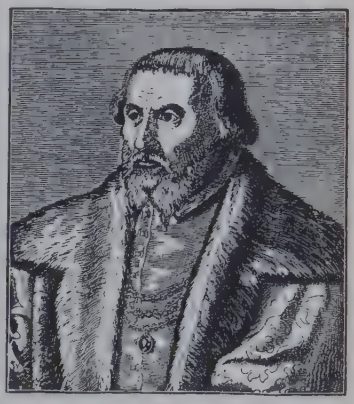

Fig. 31. — Pierandrea Mattioli, 1501–1577. (Arber, Herbals.)

In connection with the name of Matthiolus we get perhaps the earliest mention in Western Literature of the famous Dioscorides manuscript of Julia Anicia. This sumptuous manuscript was found in the hands of a Jew at Constantinople by Dusbecq, a representative of the Italian government, who was on a mission to the East. Dusbecq had secured on his own initiative a considerable number of Greek manuscripts but as the price of this one seemed very high (one hundred ducats), he begged the Emperor to give special orders to have it purchased. The Emperor complied and Dusbecq brought it to Italy, largely for the use of Matthiolus. The much-favored Matthiolus was also helped from other sources and received credit for some of the work of other writers. Collectors sent him newly discovered plants from various regions, and Luca Ghini, the most celebrated teacher of botany in Italy, who stimulated many writers but published nothing in his own name, passed over to him his extensive notes on the botany of Dioscorides.

The first edition of the " Commentaries " appeared in 1544,

two years after the publication of Fuchs' *De historia stirpium*. The pictures are notable as being original in a period when there was so much copying. Those of the earlier editions are small, but in 1565 there was published a beautiful edition with large pictures which are often very fine, showing " rich massing of foliage, fruit and flowers, suggestive of southern luxuriance. The pictures form a markedly individual contribution which is of great importance in the history of botanical illustration." (Arber.) In the various accounts of his life, Matthiolus is spoken of as a man of acrid disposition; his portrait (Fig. 31) seems to depict this quality.

Gaspard (Caspar) Bauhin (1560–1624) was the son of a French doctor who had migrated from France to escape the persecution of the Huguenots and settled at Basle, in Switzerland. Here were born two brothers, Jean and Gaspard, both of whom became famous for publications in botany, and both of whom projected very extensive works of a botanical nature which were never fully completed. Caspar, who was nineteen years younger than John, was the more famous of the two and here we deal only with his most important work. He had a liberal training at the universities of Basle, Padua, Montpellier, Paris and Tübingen. After his graduation in medicine, he was appointed professor of Greek, then of anatomy and botany, and finally of the practice of medicine, at Basle. Among other honors, he was made city physician, rector of the university and dean of the faculty. His brother John had been taught botany by Leonhard Fuchs at Tübingen, but the statement in Sachs' history of botany that Kaspar " like his elder brother Jean studied under Fuchs " is evidently a mistake, since Caspar was only six years of age at the time of Fuchs' death.

Caspar Bauhin (Fig. 32) represents the culmination of the sixteenth century movement towards a better classification of plants. The first period of descriptive botany, beginning with Bock and Valerius Cordus, is characterized by description of individual plants; with Bauhin botanical studies became more broadly comparative, and he tried, without complete success, how-

ever, to find some means of arranging plants according to their natural affinities. In this comparative method, he had been preceded by de l'Obel who attempted to group plants according to their resemblances of form. Using the form of leaves as a guide, he placed ferns among the dicotyledons, and made other similar mistakes because he used an artificial system of determining relationships. The general principle was carried much further by Bauhin, who in his *Pinax theatri botanici* (1623) classified according to likeness of habit. The *Pinax* (a chart or register) was for several generations the most widely read treatise on botany. It was a mature piece of work upon which Bauhin had labored for forty years. In it he throws to one side the medical aspects of plants and all secondary considerations, and endeavors to relate plants to one another on the basis of certain likenesses. Nevertheless, he was not able to hit upon those structural and developmental features which express their true genetic relationships. As previously indicated, the lack of knowledge of the common ancestry of plants prevented him, and for many years all his successors as well, from apprehending the true basis of relationship. The *Pinax* deals with about six thousand plants, giving terse and methodically regular descriptions in each case. In it, Bauhin removes from botany one source of great confusion. The various names given to an individual plant by classical and mediæval writers had made identification almost impossible. Bauhin worked out an exhaustive synonymy of these names, and thereby standardized the means of recognition. In naming plants according to his own method, he makes a distinction between genus and species and

Fig. 32. — Caspar Bauhin, 1560–1624. (Theatri botanici, 1658, Northwestern University Library.)

consistently employs a binary nomenclature which is the forerunner of that made current by Linnæus more than a hundred years later.

"While the herbalists were working away with quiet enthusiasm in the north, and before their labors reached their culmination in the industry of Bauhin, a greater than any of

FIG. 23.—ANDREA CESALPINO, 1519–1603. (Acta horti Bergiani, Vol. III.)

them had arisen in the south." [15] This was Andrea Cesalpino (1519–1603) whom Sachs designates as a "thinker in the presence of the plant world." Cesalpino (Fig. 33) was "greater" only in the sense that he laid down a philosophical basis for plant classification which in the seventeenth and eighteenth centuries received great attention from botanists such as Mori-

[15] Thomson, *The Science of Life.*

son, and, especially, Linnæus, and influenced the progress of botany.

He was born in 1519 at Arezzo, in Tuscany, and received his university training at Pisa where he was taught botany by the famous Luca Ghini. He took his degree in medicine when he was thirty-two years old, and for twenty years (1555–1575) was in charge of the Botanical garden which had been established at Pisa as early as 1543. In 1567 he became professor of medicine in the university where he taught botany as well as medicine; Galileo attended his lectures. At the age of sixty-three he went to Rome to become physician to Pope Clement VIII and a professor at the Sapienza. Although he made many observations on plants he was essentially a theorist; delighting in controversies, he got into some theological difficulties from which, however, he extricated himself to the satisfaction of the Church. He seems to have been a very reserved character but to have possessed great confidence in his own powers, taking no notice of the botanical work of his contemporaries, who, in turn, neglected his. The Italians have claimed for him, on insufficient grounds, the discovery of the circulation of the blood. We shall return to this question in the chapter on Harvey.

During his life and for some time thereafter, Cesalpino's work received little attention, but Linnæus, in his *Classes plantarum* (1738), when giving a review of all the systems of classification proposed before his time, gave first rank to that of Cesalpino. This had the effect of placing him in a position of prominence and thereafter he probably received more attention than the comparative merits of his system would justify. Sachs says that Cesalpino took the wrong path and made highly unnatural groupings. "He believed that he could establish on premeditated grounds the marks which indicate natural affinities," but the results obtained by himself in the application of his principles are quite unsatisfactory. "Not a single new group founded on natural affinities is established, which does not appear already in the herbals of Germany and the Netherlands."

Cesalpino's book, *De plantis, libri XVI,* is a quarto published

at Florence in 1583. Fifteen of the sixteen books contain descriptions of fifteen hundred twenty plants arranged in fifteen classes and occupy six hundred pages. The author's special contribution to general botany, however, and to the principles of classification, is to be found in the first book, which consists of only thirty pages. He makes many observations on the fruits and seeds of different plants and on the prehensile organs of climbing plants; observations that are not purely descriptive but comparative. He proceeds on the basis of reasoning to select the characteristics upon which he thinks classification should be based. He shows that differences in the roots, the leaves and the flowers cannot be relied upon, and finally selects the organs of fructification.

On account of the enunciation of this general principle, Linnæus calls him the first true systematist of botany (*primus verus systematicus*).

CHAPTER IX

VESALIUS AND THE OVERTHROW OF AUTHORITY IN SCIENCE

The sixteenth century commands our attention as the era in which the scientific spirit got a firm foothold. These were thought-stirring times; printing had effected the spread of general intelligence, the so-called New Learning was making itself felt, the noonday of the Renaissance was arriving and the movement of the Reformation was set on foot.

The gradual emancipation of the human intellect from the bonds of a strongly entrenched authority extends over two or three centuries, but, for natural science, the summit was reached in 1543 when Andreas Vesalius presented to the world in printed form his book on the structure of the human body. On account of the influence of Vesalius on all subsequent investigations of nature, this was a major event for the history of science.

The date 1543 is, for biology, the natural terminus of the Middle Ages and the beginning of a new era. Owing to the gradual development of human institutions, the selection of a date is more or less arbitrary — one situation does not terminate abruptly and give way to another; they merge until, finally, the new order becomes established. The dates 1453 and 1492, commonly used to mark the end of mediæval and the beginning of modern times, do not correspond with any marked scientific advancement, but the date 1543 does so correspond. When Constantinople fell into the hands of the Turks, in 1453, there was a renewal of migration to the West by Eastern scholars; and the Greek manuscripts which they brought, added to those already there, quickened the revival of classical learning. Also, after the discovery of the New World by Columbus, in 1492, there began an era of geographical exploration and colonial ex-

pansion. Both of these events provided a stimulus to thought, but they were more generic in their influence on intellectual development than the work of Vesalius, which was more specific for the development of scientific method. The method pursued by Vesalius, and his onslaught against the authority of Galen in anatomy, resulted in overturning dependence on authority as a means of ascertaining truth and substituted therefor observation and reason.

The year 1543 is also memorable in science for the publication of the long delayed work of Nicholas Copernicus on the "Revolutions of the Heavenly Bodies" (*De revolutionibus orbium cœlestium*), setting forth the doctrine of a stationary sun as the center about which revolve the earth and other planets, as well as the idea of the daily revolution of the earth on its axis. This conception of the solar system, although matured thirty years earlier by Copernicus, was published just as his life was ebbing to its close and he corrected the proofs on his deathbed. The theory was rejected for many years, so that Copernicus had little influence on the thought of the sixteenth century; on the other hand, the observational work of Vesalius had immediate influence and took a greater part in the intellectual revival on its scientific side.

The mere fact that Vesalius' observations were on the human body was favorable to a quick response. Had the subject been plants or the structure of lower animals, it would not have challenged notice as it did. But it opened questions of a biological and philosophical nature touching human life so closely that it startled the mind into attention. Knowledge of the structure of the human body is indispensable for medicine and surgery, but the discoveries also aroused public curiosity and soon anatomical plates of skeletons, etc., were displayed in barber shops and public baths. Vesalius' accurate and detailed study of the structure of man's body had wider influence than a mere advance in medical science; it laid the foundation for more accurate studies of the structure of organized beings — in other words, it opened the way for the science of morphology.

It should be noted, though perhaps one should not stress the point at this juncture, that this new science was opened from the wrong end. For practical reasons, observations in anatomy began with the architecture of the human body and that of animals which in structure are related closely to man. Morphological studies started with the more complex animals instead of the simpler ones, and, ultimately, this gave rise to many misunderstandings in comparative anatomy because the structure of man became the recognized type to which all others were referred, though, on account of his derivation and development, his structure represents the greatest modification of the vertebrate type.

To understand the influence of Vesalius we should keep in mind the limitations surrounding the study of anatomy in the time of Galen, and the circumstances under which the practice of dissection was revived after his time. As we have seen, Galen (131–201), one of the monumental figures in the history of natural science, the last of the great anatomists of antiquity and a scientist whose powers as an investigator were in no degree secondary to those of Vesalius, worked under very unfavorable circumstances. Since the time of Herophilus and Erasistratus, the dissection of the human body had been proscribed, and he was obliged to make his anatomical observations on dogs, swine, oxen and the Barbary ape and to expound the structure of the human body "on the faith of observations made on lower animals." Soon after his time came the overthrow of ancient civilization and the decline of all forms of scientific investigation. By later generations, he was set up as the supreme authority in medicine, including anatomy and physiology. For twelve centuries his works exerted the greatest influence on natural science, and his contributions to anatomy were accepted as finalities up to the time of Vesalius. Galen himself was not to blame for this turn of affairs; it is often overlooked that Vesalius expressed admiration for Galen's work where it was right, though he was merciless in his criticism of his mistakes.

A thousand years after Galen, when human thinking took an upward turn in the thirteenth century, there were men who saw

clearly the need of return to scientific observation. One of these was the enlightened ruler, Frederick II (1194–1250), King of Sicily and Emperor of the Holy Roman Empire, "patron of arts and sciences, warrior and statesman." To provide for the welfare of his subjects, as well as to favor the extension of knowledge, he decreed, in 1231, "that no surgeon be admitted to practice unless he be learned in the anatomy of the human body." The same year he promulgated a law providing for the public dissection of the human body at least once in five years, at Salerno, in the presence of the physicians and surgeons of the kingdom. In this way the dissection of the body was legalized at Salerno and other states and cities followed in due course. In 1308 the college of medicine of Venice (at Padua) was authorized to dissect a human body once a year. It is not essential to mention the dates at which dissections were legalized in other places, but there is reason to believe that in the early years of the fourteenth century the practical study of anatomy had became habitual in the medical schools of Italy.

Just as other aspects of the Renaissance developed first in Italy, so also did the scientific revival with which we are especially concerned. Medicine, "the foster-mother of many sciences," had a pronounced development in Italy. From the establishment of the medical school at Salerno in the ninth century the Italians led in the teaching of anatomy, and in the first part of the sixteenth century Vesalius went to Padua for his training.

FOUR FORERUNNERS OF VESALIUS

Mondino. Of his forerunners there are three in Italy and one in France who require brief notice. These are Mondino, Leonardo da Vinci, Berengarius da Carpi, of Italy, and Jacobus Sylvius, of France.

Mondino (graduated in medicine, 1290; died, 1326) was a celebrated teacher of anatomy in the university of Bologna, who in 1316 issued a small book on dissection. In this book he mentions specifically the dissection of two female bodies. This fact has given rise to the opinion that his dissection of the human

cadaver was quite limited, but more careful scrutiny of his text shows that his mention of the two female bodies is for comparison of the size of the uteri with that of a pregnant sow which he dissected about the same time. On a later page of his book, Mondino refers to demonstrations he had made on "the first, second, third, and fourth" cadavers. Also, Guy de Chauliac, who studied at Bologna under the successor of Mondino, says that Mondino had demonstrated many times on the human cadaver. We know that he was taught dissection by Taddeo, and we conclude that "the occasional dissection of the human body was probably a matter of routine at Bologna during the student days of Mondino and that he merely brought to an established practice a new enthusiasm and possibly a better method." (Pilcher.)

Mondino was a great favorite with the students who came under his instruction. He seems to have been a man of engaging personality gifted with powers of clear exposition. His book was a small manual (originally forty-four quarto pages) to simplify the teaching of anatomy, and it was often used as an introduction to Galen's anatomical writings. It was so highly esteemed that it remained in general use for upwards of two centuries, and in Italy it came to be prescribed by legislation as the required text-book of anatomy. It is not, however, an original treatise based on personal observation. Mondino merely brings into a brief and systematic form the teachings of Galen with some modifications of his own, and the key to the influence of the book is not originality but its wide circulation. After Mondino there seems to have been a decline in the teaching of anatomy, and often the book was read without any dissection; at other times dogs and other animals were used for demonstrations while the teacher read from the book. Thus Mondino did not succeed in overcoming the influence of tradition, and the circulation of his treatise resulted in bringing in a new book-authority.

The book was first printed as a small folio at Padua in 1478, and between that date and 1580, when the last edition was pub-

lished, not less than thirty-three editions, including translations, are known to have been printed. The Melerstat edition, printed without date at Leipzig about 1493, was provided with a single woodcut (Fig. 34), which possesses some general interest since it represents the method of teaching anatomy in the pre-Vesalian

Fig. 34. — The Single Picture in the Melerstat Edition of Mundinus, Leipzig, 1493. (Surgeon General's Library.)

period. The teacher (possibly intended for Mondino), clothed in academic costume, sits in a chair, reading from a text while the demonstrator under his direction exhibits the parts read about. It is known that Mondino had two assistants, one of

whom was a young girl named Alessandra Giliani, who manifested an extraordinary interest in learning and a passion for anatomy. She died, shortly after Mondino, in 1326, at the age of nineteen. This young woman had unusual manual dexterity and patience, cleaning and exposing blood vessels even to their minutest twigs and coloring the same. In this picture, the demonstrator in front of the teacher is probably intended to represent Alessandra Giliani; the face, the torso and the waist line suggest a female figure. It is frequently said that the scene is laid in the open air, but this effect is probably due to the introduction by the artist of a conventional background of landscape, a practice common at this period, and shown in the anatomical pictures of Vesalius, as well as in many other anatomical illustrations of the fifteenth and sixteenth centuries. Printed pictures of this nature, exhibiting a dissection scene, are very common. The first picture of the kind is widely credited by bibliographers to Ketham's *Fasciculus medicinæ,* 1491, but an earlier one appeared in 1482 in a French translation of Bartholomew's *Properties of Things.*[1]

Though the most ancient examples have been lost, we know that anatomical drawing was attempted as early as two or three centuries before the introduction of printing. Pen, crayon and chalk drawings of this kind are found in the medical manuscripts stored in the libraries at Berlin, Paris, Oxford, Munich, and other places. A rich series of anatomical sketches has been brought to light by Karl Sudhoff and his collaborators, and reproduced by photographic methods in the *Studien zur Geschichte der Medizin* and in the *Archiv für Geschichte der Medizin.* These resurrected manuscript sketches throw a flood of light on the sources of early anatomical illustrations. A genetic connection has been established between some of them and the earliest printed anatomical figures.

Leonardo da Vinci. The anatomical sketches of Leonardo da Vinci, although not fully published until the twentieth cen-

[1] For several similar pictures differing in detail see Chievitz, Singer and others.

tury, are so extraordinary that they should be considered at this point. Most of these drawings were prepared about 1510, some thirty years before those of Vesalius, and, furthermore, we have a memorandum of Leonardo to show that he was planning a book on the "human body" as early as 1489. At any rate it seems to be established that he had studied anatomy independently before he became associated with the anatomist Antonio Della Torre, and he continued to make dissections after their relations were dissolved about 1506. The nature and the quality of his numerous sketches from actual dissections, entitle Leonardo to recognition as by far the greatest practical anatomist before Vesalius. For a long time he was regarded, in anatomy, merely as one of those dissecting artists, who flayed bodies and studied the surface arrangement of muscles in order to depict more accurately the human body, but in reality he was far more than this, working out the internal anatomy with great detail. His sketches showing the structure of the heart and of the vascular system are especially numerous and detailed; he gives excellent pictures of the bones drawn from different aspects; of the deeper layers of the muscles with their attachments; a number of cross-sections of the leg at different levels; correct delineations of the viscera; of the brain and of the nerves. His pictures dealing with the generative function show uteri cut open, with contained fœtuses and the placental connection.

Leonardo projected a comprehensive work on anatomy, of which he speaks in his "History of Painting," and also in his manuscript notes. The notes and drawings bear testimony that this treatise was not designed merely for artists, but was to be a work for medical students and for the professional anatomist as well. About 1510, Antonia de Beatis had from Leonardo's own lips the statement that he had dissected no less than thirty human bodies both male and female. But no finished manuscript is known. What must constitute, however, the major part of the working-drawings and the notes for the projected work are preserved as a part of the manuscript collection of the Royal Library at Windsor Castle. These manuscript sketches were

published at Paris in 1898 and at Turin in 1901, in facsimile both as regards the sketches and the paper upon which they are drawn. Again, they were printed at Christiania in six sumptuous volumes from 1911 to 1916. In the Paris edition the notes for volume one are translated into French, and in the Christiania edition all the notes into English and German.

The range of the drawings is astonishing; the entire collection embraces more than seven hundred fifty separate sketches of human anatomy, some of them being several times repeated. The notes, on the same sheets as the sketches, and written in a fine hand from right to left (mirror writing) give descriptions of the figures and record passing thoughts and memoranda together with general reflections regarding the plan of his projected book. This legacy from Leonardo is worthy of more extended consideration, but for lack of space, a single picture (Fig. 35) must suffice.

In all history, no previous observer had accomplished anything comparable to the achievement of Leonardo in anatomy. An examination of his sketches and notes makes it clear that "Leonardo pursued methods of research essentially the same as ours. He did not publish his methods and conclusions in the conventional way, but we know there were other ways open by which he could reach and influence his contemporaries." Just what influence he actually had is conjectural, but if his anatomical drawing had been given to the world in his day, they would have won for him a definite and commanding place in the history of anatomy, and doubtless he would be recognized today as, before Vesalius, the restorer of anatomy. In fact a controversy has, even so, been started (1902) as to whether Vesalius knew of Leonardo's sketches and made use of them. But the consideration of this question must be postponed until we have reviewed the contribution of Vesalius to anatomy.

Berengario. Berengario da Carpi, who was professor of surgery at Bologna from 1502 to 1527, and died in 1550, has often been heralded as the greatest of the pre-Vesalian anatomists. He seems to have acquired merit in the eyes of writers on

anatomy on account of his alleged dissection of more than one hundred bodies. The first anatomical publication of Berengario was an extensive series of commentaries on Mondino, published

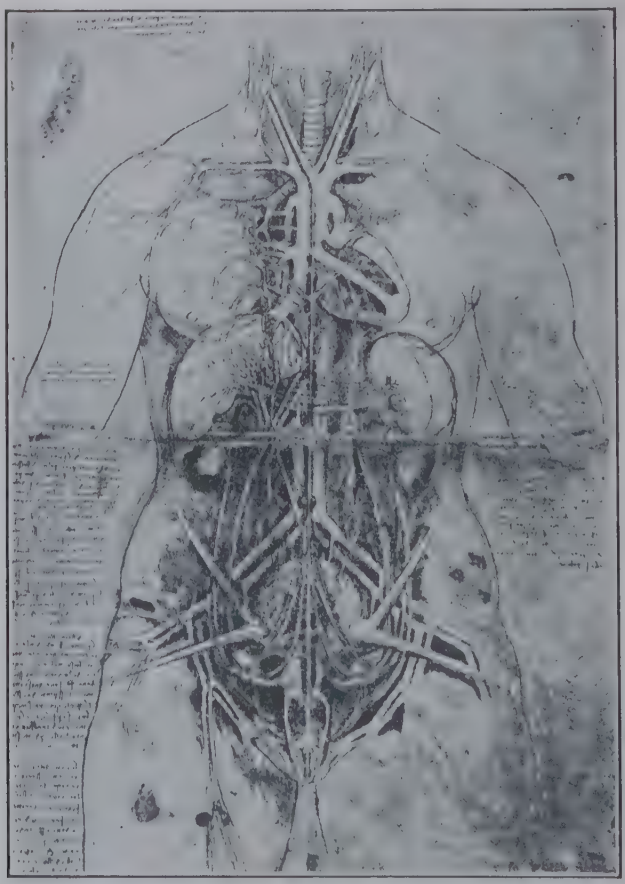

FIG. 35. — ANATOMICAL SKETCH FROM I MANOSCRITTI DI LEONARDO DA VINCI, 1510. (From the Paris *facsimile* edition, John Crerar Library.)

at Bologna in 1521. In this, the text of Mondino is printed in larger type and the forty commentaries in smaller, but so extensive are the annotations, that the book is brought up to a thick

quarto volume of 1056 pages. His commentaries at times contain corrections to Mondino and show the results of some personal observations mixed with dialectic compilations from the earlier writers. Among his contributions are the first description of the vermiform appendix, the denial of the existence of a 'rete mirabile' below the brain and of pores in the septum of the heart. He describes certain bones and sinuses of the head, the connection of the brain vesicles with the canal of the spinal cord, etc. The text is better than the twenty-one illustrations with which it is provided. The cuts are not original nor are they based on good observation with the exception of those of the bones of the hand and foot, which from close resemblance one suspects are taken from the similar sketches of Leonardo. The best muscle-pictures — those of the muscles of the abdominal wall — are derived from those published as early as 1496 in Peter of Abano's *Conciliator*. It is, however, altogether likely that the cuts were inserted by the publisher from such pictures as were available.

Soon after preparing the commentaries on Mondino, Berengario branched out for himself and published in 1522 an introduction to anatomy, designated *Isagogæ breves*, etc. A modified edition (one hundred sixty pages) followed in 1523. Copies of these books, as well as of the rare "Commentaries" of 1521, are in the Surgeon General's Library at Washington. There is also in that library a cheap student's edition of the "Introduction," dated 1530, which throws some light on the question of student-texts of the period. This small pocket edition, with a letter-press of $2\frac{3}{8}$ x $4\frac{1}{4}$ inches, is cheaply printed and bound in paper boards. The twenty-four illustrations which it contains are small, wretched copies of those in the larger "Introduction."

If it be true, as alleged, that Berengario dissected a hundred bodies, the work must have been hurriedly done. His treatise does not impress one as a piece of strong, original work and he published no sketches made from his own dissections. Apparently he started in the right way but did not succeed in establishing a better method of study in the domain of anatomy.

Jacobus Sylvius. We pass now from Italy to France where Jacobus Sylvius [2] (1478–1555), one of the teachers of Vesalius, became distinguished as a teacher of anatomy. His connection with Vesalius makes it of prime importance to do justice to his services, more especially since Vesalius made indiscriminate criticisms of his teacher which have generally been accepted without further testimony. Jacobus Sylvius (Fig. 36) evidently understood what was essential to a reform in the teaching of anatomy. In his introduction to anatomy he is very explicit in advising that the study always be pursued by eye and touch, and when possible from the human body. He says that anatomy can never be taught by reading and description. Nevertheless, the limitations under which he labored, the force of habit, and the practical difficulty of obtaining material, led him to teach the subject on a lower level than he theoretically advocated. He read Galen to his classes, and the limited number of dissections in his lecture room were made usually by unskilled barbers on the bodies of dogs. He was very clear as an expounder of the subject, and made an important contribution in assigning special names to muscles and blood vessels; Galen had designated muscles and other parts by numbers, while Sylvius gave them specific names some of which are in use today. He was, however,

FIG. 36. — JACOBUS SYLVIUS, 1478–1555, TEACHER OF VESALIUS. (Chievitz, *Anatomiens Historie.*)

[2] The work of this man has been confused with that of Franciscus Sylvius (1614–1672) who lived about a century later in Holland. The analysis of the original sources by Dr. Frank Baker has served to correct many misconceptions regarding the "two Sylviuses." Jacobus Sylvius did not especially investigate the brain nor, as so frequently stated, were the *fissure* and *artery* of *Sylvius* named in his honor. On the contrary Franciscus Sylvius described these parts for the first time about 1641, and they bear his name.

such a worshipper of Galen that in actual practice his method of teaching remained essentially that of authority, and the progress of the science of anatomy awaited an innovator.

COMMENT

Such was the condition of the science when Vesalius came upon the stage.[3] Even a brief review of pre-Vesalian anatomy brings into notice the relatively slow progress. This was the period of the awakening of the scientific spirit, but the drama of intellectual progress does not unfold as rapidly as we might expect. Why, after the revival of dissection under Mondino, and why, especially, after the introduction of printing, was there not more rapid progress? Some seek to find an answer in the difficulty of getting material for dissection and others in the opposition of the Church, but neither of these alleged hindrances existed.[4] That which held anatomical science in check was not so much the lack of opportunity to dissect as the mental habit of the time. The disposition to dissect was not especially strong. The effects of tradition and of previous education had to be overcome. Those who would have done better under gifted and inspired leaders were perplexed and too closely bound by the mental habit of the time to map out and follow an independent course. Thus the retarding influence was generic rather than specific. Independent spirits of great originality were rare then, as now, and the habit of imitation was strong. Leonardo was the only man before Vesalius whose product exhibits great originality and independence. His anatomical work was on the plane

[3] There were other dissectors and teachers of anatomy of the period whose names we have omitted, but who would require consideration in a more detailed account of pre-Vesalian anatomy. (See Charles Singer, — *Studies in the History and Method of Science*, Vol. I, 1917, p. 79.)

[4] The practice of dissection by medical men was not as actively opposed by the Church as is generally supposed. A superficial reading of the bull of Pope Boniface *de sepultis*, issued in 1300, has led to the statement that it was directed against the practice of dissecting for scientific purposes, but it was, in reality, a proscription of the practice of dismembering the bodies of dead Crusaders, in order that their bones might be more readily transported home for burial in consecrated ground.

of that of Vesalius, but, we believe, his treatise was never completed and certainly his sketches were not printed until long after.

Vesalius succeeded where others had failed; it is true that the way had been prepared for him, at the same time we must recognize that he was well fitted to do battle against tradition — strong in body, in mind and in purpose, gifted and forceful. Furthermore, his work was marked by concentration and by the high moral quality of fidelity to truth. Through his efforts before he was thirty years of age, the idol of authority in learning had been shattered, and, mainly through his persistence, the method indispensable to the progress of science had been established.

VESALIUS

Andreas Vesalius was born in Brussels on the last day of the year, 1514, of an ancestry of physicians and learned men, from whom he inherited his leaning towards scientific pursuits. Early in life he exhibited a passion for anatomy; he dissected birds, rabbits, dogs, and other animals. Although having a strong inclination in this direction, he was not a man of a single talent. He was schooled in all the learning of his time, and his earliest publication was a translation from the Greek of the ninth medical book of *Rhazes*. After his early training at Brussels and at the university of Louvain, in 1533, at the age of eighteen, he went to Paris to study medicine, where, in anatomy, he came under Sylvius and Günther.

His impetuous nature was shown in the amphitheatre of Sylvius, where, at the third lecture, he pushed aside the clumsy surgeon barbers and himself exposed the parts in the proper manner. He could not be satisfied with the printed page; he must see with his own eyes, must grasp through his own senses the facts of anatomical structure. This demand of his nature shows not only how impatient he was with sham, but also how much more he possessed the spirit of the investigator than other men of his time.

After three years at the French Capital, owing to wars in Belgium, he went back to Louvain without obtaining his medical degree. After a short experience as surgeon on the battle-field, he went to Padua whither he was attracted by reports of the opportunities for practical dissection that he so much desired to undertake. His talents were recognized and just after receiving his degree of Doctor of Medicine in 1537, he was given an appointment in surgery, and placed in charge of the teaching of anatomy at the university.

The sympathetic and graphic description of this period of his career by Sir Michael Foster is so good that it is well worth quoting: "He at once began to teach anatomy in his own new way. Not to unskilled, ignorant barbers would he intrust the task of laying bare before the students the secrets of the human frame; his own hand, and his own hand alone, was cunning enough to track out the pattern of the structures which day by day were becoming more clear to him. Following venerated customs, he began his academic labors by 'reading' Galen, as others had done before him, using his dissections to illustrate what Galen had said. But, time after time, the body on the table said something different from that which Galen had written.

"He tried to do what others had done before him — he tried to believe Galen rather than his own eyes, but his eyes were too strong for him; and in the end he cast Galen and his writings to the winds, and taught only what he himself had seen and what he could make his students see, too. Thus he brought into anatomy the new spirit of the time, and the men of the time, the young men of the time, answered the new voice. Students flocked to his lectures; his hearers amounted, it is said, to some five hundred, and an enlightened Senate recognized his worth by repeatedly raising his emoluments.

"Five years he thus spent in untiring labors at Padua. Five years he wrought, not weaving a web of fancied thought, but patiently disentangling the pattern of the texture of the human body, trusting to the words of no master, admitting nothing but that which he himself had seen; and at the end of the five years,

in 1542, while he was not as yet twenty-eight years of age, he was able to write the dedication to Charles V of a folio work entitled the 'Structure of the Human Body,' adorned with many plates and woodcuts, which appeared at Basel in the following year, 1543."

This classic with the Latin title, *De humani corporis fabrica,* requires some special notice; but first let us have a portrait of Vesalius, in 1542, at the age of twenty-eight. Fig. 37 shows a reproduction of the portrait with which his book is provided. He is represented in academic costume, probably that which he wore at lectures, in the act of demonstrating the muscles of the arm. The picture is reduced, and in the reduction loses something of the force of the original. We see a strong, independent, self-willed countenance; what his features lack in refinement they make up in force; not an artistic nor poetic face, but the face of a man of action with scholarly training.

His great book. The book of Vesalius laid the foundations of structural studies in biology. It is rather more than a landmark in the progress of that science — it created an epoch. On account of the highly artistic plates with which it is illustrated, it is of interest to others besides the anatomists. For executing the plates Vesalius secured the service of a fellow-countryman, John Stephen de Calcar, who was one of the most gifted pupils of Titian. The drawings are of such high quality that for a long time they were ascribed to Titian himself. The artist has attempted to soften the necessarily prosaic nature of anatomical illustrations by introducing an artistic background of landscape of varied features, with bridges, roads, streams, buildings, etc. The employment of such a background even in portrait painting was not uncommon, as in Leonardo da Vinci's famous *Mona Lisa,* with its perspective of water, rocks, etc.

Fig. 38 will give an idea on a small scale of one of the plates in the book of Vesalius. The plates in the original are of folio size and frequently represent a colossal figure in the foreground, with a landscape showing in the background between the limbs

FIG. 37. — ANDREAS VESALIUS, 1514–1564. (Frontispiece, *facsimile* edition of 1728, Northwestern University Library.)

and at the sides of the figure. There is considerable variety as regards the background, no two plates being alike. In the skele-

FIG. 38. — ANATOMICAL SKETCH FROM VESALIUS' *Fabrica*.
(Photographed and reduced from the same book.)

ton (Fig. 39), shown in three aspects in the book, the bones are well drawn, but to take away from the forbidding nature of the

subject, the artist gives it a fanciful pose. In the original edition of 1543 the illustrations are not arranged as inserts, but are dis-

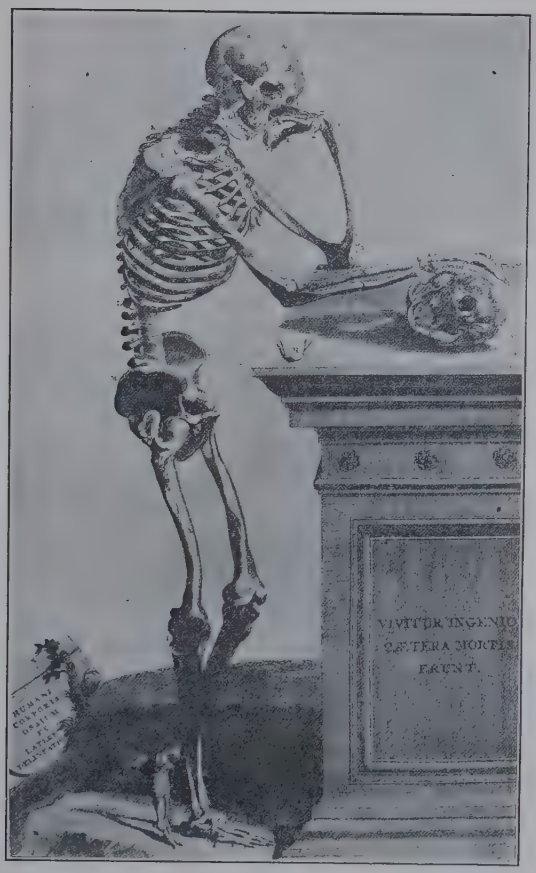

Fig. 39. — The Skeleton from the Same Book.

tributed through the text. No plates of such merit had appeared before these; in fact, they are now the earliest generally known drawings in anatomy, although woodcuts representing anatomical

figures were published in at least fifteen separate works before 1543.[5] The chapters are introduced with an initial letter having curious anatomical figures in miniature, some of which are shown in Fig. 40.

Fig. 40. — Initial Letters from the *Fabrica* of 1543. (John Crerar Library.)

Previous to the publication of the complete work, Vesalius, in 1538, had published six tables of anatomy, and, in 1555, he brought out a new edition of the *Fabrica*, with slight additions, especially in reference to physiology, which will be spoken of more fully in the chapter on William Harvey.

The *Fabrica* of Vesalius was a piece of careful, honest work, the moral influence of which must not be overlooked. At any moment in the world's history, work of marked sincerity exercises a wholesome influence, but at this particular stage of intellectual development such work was an innovation, and its significance for progress was wider and deeper than it might have been under different circumstances.

"While written in Latin, the *Fabrica* is truly vernacular in the sweeping scorn and violence of its language in dealing with Galenical and other superstitions." (Garrison.) In it Vesalius corrected some two hundred anatomical errors of Galen. Yet, though the book "recreated the

[5] See Garrison, "History of Medicine"; Locy, "Anatomical Illustration Before Vesalius," in the *Journal of Morphology*, 1911; and Singer, in *Studies in the History and Method of Science*, Vol. I.

whole gross anatomy of the human body," it has only recently been translated for the first time.[6]

Charged with Plagiarism. As soon as published the claims of Vesalius were vigorously assailed because they were opposed to Galen; but his integrity and originality were not questioned by his contemporaries, nor indeed by anyone till several centuries later. Jackscath, a veterinarian of Tilsit, in 1902, and again in 1904, claimed that the *Fabrica* of Vesalius was a wholesale plagiarism from Leonardo da Vinci. In 1903, von Toply of Vienna contended that Vesalius had borrowed without acknowledgment certain pictures of the skeleton from Estienne (Stephanus, 1539). But investigation of this last claim, says McMurrich, " shows that the charge should be reversed." Among students of the history of anatomy who have taken part in the belated controversy as to whether Vesalius plagiarized from Leonardo are Sudhoff, Garrison, McMurrich and Roth. The question involves technicalities, but the writer believes that the weight of evidence is strongly against the charge. Whatever else was said against Vesalius by acrimonious opponents, none of the contemporary or nearly contemporary writers accuse him of this offense. Vasari, whose *Lives of the Painters* was published fourteen years before the death of Vesalius, and who wrote on Leonardo, made no suggestion of this nature. John Caius, the second founder of Gonville and Caius college, Cambridge, lived in the same house with Vesalius at Padua " for eight months, during which time he wrote and drew his books *de fabrica humani corporis*."

OPPOSITION TO VESALIUS

Vesalius' utterances were opposed from all sides. Not only did the ecclesiastics contend that he was disseminating false and harmful doctrine, but the medical men from whom he might have expected sympathy and support violently opposed his teachings. Many amusing arguments were brought forward to discredit him and to uphold the authority of Galen. In contradic-

[6] I refer to the forthcoming translation into English by Professor William Wright and Mr. Foate.

tion to the teaching of the latter, Vesalius showed that in the human body the lower jaw is a single bone, not divided as it is in the dog and other lower mammals. He showed that the sternum, or breast bone, has three parts instead of eight; that the thigh bones are straight, and not curved as they are in the dog. Sylvius, however, his old teacher and one of his bitterest opponents, declared (it seems incredible) that the human body had undergone changes in structure since the time of Galen; "he asserted that the straight thigh bones, which, as every one saw, were not curved in accordance with the teaching of Galen, were the result of the narrow trousers of his contemporaries, and that they must have been curved in their natural condition, when uninterfered with by art!"

The theologians also found points for contention. It was a widely accepted dogma that man had one less rib on one side, because from the Scriptural account Eve was formed from one of Adam's ribs. Vesalius, however, found an equal number of ribs on each side. Consequently, his teachings were contrary to prevailing dogma. But he went even further; he treated dogma with levity. It was generally believed at this time that there was in the body an indestructible resurrection-bone [7] which formed the nucleus of the resurrection-body. Vesalius said that he would leave the question of the existence of such a bone to the theologians, as it did not appear to him to be an anatomical question.

The hand of the Church was heavy upon him, and the hatred shown in attacks from various quarters threw Vesalius into a state of despondency and anger. In this frame of mind he destroyed manuscripts upon which he had expended much labor. His disappointment in the reception of his work probably had much to do in deciding him to relinquish his professorship and accept the post of court physician to the emperor, Charles V, then residing in Spain. After the abdication of Charles, and

[7] This bone called *Luz* has been variously located as in the "sacrum, as the eighteenth vertebra, as coccyx, as one of the bones of the head and as ossicle of the great toe. From the medieval descriptions of its size, shape and hardness it was probably the latter." (Garrison.)

the division of his empire, Vesalius remained with Philip II who succeeded to the Spanish throne. But though he waxed rich and famous, he was always under the suspicion of the clerical powers, who from time to time found opportunities of attacking him. The circumstances of his leaving Spain are not definitely known. We know that he chafed under the restraints of Court routine and that he sighed for opportunity to return to the practical study of anatomy which was denied him in Spain. He wrote: "I still live in hope that at some time or other, by some good fortune I may once more be able to study that true Bible, as we count it, of the human body and of the nature of man."[8] In 1561 he was excited by receiving the anatomical observations of Fallopio the "greedy reading" of which vividly brought back to him the delights of scientific investigation. In 1563 he suddenly determined to make a pilgrimage to Jerusalem, probably as an excuse for getting away from the Spanish Court after nineteen years.

"On his way to Jerusalem he visited Venice and renewed his intercourse with scientific friends." It is also said that while on this pilgrimage he was offered his old post of professor of anatomy at Padua, to succeed Fallopio who had died there in 1562. But, this longed-for restoration to academic life was not to be, for, on his way back from the Holy Land, he was taken ill, was put ashore on the island of Zante, one of the Ionian Islands, and there, at the age of fifty, he passed away.

SOME CONTEMPORARY ANATOMISTS

Eustachi and Fallopio, two contemporaries of Vesalius, should be mentioned; their names are in current use in connection with the Eustachian tube and the Fallopian tubes, and by some writers they are considered as the reformers of anatomy along with Vesalius. But the latter was a greater man than either and his influence was more far-reaching. He reformed the entire subject of anatomy, while the names of Eustachi and Fallopio are connected especially with a smaller part of the field. Eustachius

[8] Translation of Sir Michael Foster.

described the Eustachian tube of the ear and gave especial attention to sense organs; Fallopius made special investigations upon the viscera, and described the Fallopian tubes. Besides these special investigations, however, both wrote on anatomy in general.

Fallopius, (the Latin form of his name, 1523–1562), was a favorite and loyal pupil of Vesalius and succeeded to the chair

FIG. 41. — GABRIELLE FALLOPIO, 1523–1562. (Smith collection of portraits, Newberry Library.)

of anatomy at Padua when Vesalius withdrew. His anatomical observations did not always agree with those of his master, but he was a considerate, polite man, and when he opposed his former teacher, his criticisms were couched in respectful terms.

Eustachius, professor of anatomy at Rome, was of the opposite type, harsh, and violent, and assailed Vesalius with virulence. Born between 1500 and 1510, of a patrician family, and living till 1574, he dissected the human body with great care and prepared a series of forty-six plates, some of which, at least,

were drawn by his own hand. They are stiff and formal in execution but more exact than those of Vesalius. These plates were not published till 1714; they were the first copper plates to illustrate an anatomical treatise though engravings on copper had been used earlier in botanical and zoölogical treatises. What influence Eustachius may be said to have had on the progress of anatomy was thus delayed until the eighteenth century.

Cut 42 shows a picture of Eustachius in his amphitheater at Rome, in 1561, and Fig. 43 his portrait from the sketch of his

Fig. 42. — Eustachi in His Anatomical Theater at Rome. (*Tabulæ anatomicæ*, 1722.)

life by Bilanconi (1913). There is a bust portrait of Eustachius at the entrance to the Scuola di Sapienzia where he taught.

The anatomist Colombo (1516–1559) is spoken of by Foster and others as a scheming detractor of Vesalius, a tricky and disloyal character, who undertook (unsuccessfully) to undermine Vesalius while acting as his deputy, and to direct attention to himself as the greater anatomist. Colombo (Columbus) is sometimes spoken of as the discoverer of the lesser circulation through the lungs, a claim which will be considered in dealing with Harvey's demonstration of the circulation of the blood.

It should be remembered that all the followers of Vesalius had the advantage of his sketches and observations. Pioneers and path-breakers are under the special handicap of working in virgin territory, and make more errors than they would in following another's survey of the same field. It takes much less creative force to correct the errors of a first survey than to make the original discoveries. Everything considered, Vesalius is deserving of the position assigned to him. He was great in a larger sense than some of his contemporaries who were equally good observers, for it was his researches, in particular, which reëstablished scientific method and made further progress possible. Vesalius was no more exempt from errors than any other man, but his errors were corrected, not by an appeal to authority, but by the method which he had founded. It speaks well of his influence that even his admirers did not attempt to make of him another Galen of unfailing authority. His great claim to renown is, not that his work outshone all other work (even that of Galen) in accuracy and brilliancy, but that he overthrew dependence on authority and reëstablished the scientific method of ascertaining truth. It was the method of Aristotle and Galen given anew to the world.

FIG. 43. — BARTOLOMEO EUSTACHI, 1524–1574. (From his Life by Bilanconi.)

CHAPTER X

WILLIAM HARVEY AND EXPERIMENTAL OBSERVATION

After the splendid observations of Vesalius, revealing more exactly the construction of the human body, William Harvey took the next great forward step by experimentally determining the office of some of the structures which Vesalius had so clearly exposed. The work of Harvey was complementary to that of Vesalius, and taken together the contributions of the two laid the foundations of the modern method of investigating organic nature. The results they attained and the influence of their methods are of especial interest because they stand at the beginning of a new era of natural science. Although the anatomical observations of Vesalius and the experiments of Harvey were applied mainly to the human body, they set the pattern, and they served to open the entire field of structural studies and of experimental observations on living organisms.

In what sense the studies of Vesalius and Harvey were complementary will be better understood when we remember that there are two aspects of living organisms that should be kept in view in all biological investigation; these are, first, structure, and second, function. Just as the knowledge of the construction of a machine is necessary to understand its action, so the anatomical analysis of an organ must precede a knowledge of its office, and even the physiological searcher finds it necessary to come to an understanding of the "physiological anatomy" before he can direct his experiments with intelligence. The work of the anatomist concerns the statics of the body, that of the physiologist the dynamics; they must be properly combined to give a complete picture of the living organism.

These two aspects are continually overlapping in the work of men of commanding importance and it is to be remembered that the observations of Vesalius were not confined exclusively to structure; following the practice of Galen, he engaged in vivisection, and by experimental section of the spinal cord he verified some of Galen's conclusions. Vesalius made a few other experiments of a physiological nature, but his work was chiefly structural. The work of Harvey on the other hand was mainly physiological although he was a profound student of structure as well.

It is rather misleading to state without qualifications that the Galenical anatomy and physiology was overthrown by Vesalius and Harvey, since it seems to imply that they were men of better mental endowment, and tends to depreciate Galen who worked under very different conditions. As we have pointed out before, no one can read Galen's writings without recognizing that he was a great experimental investigator. His physiological experiments were no random attempts but were well-planned and carefully executed (cf. p. 69). He actually performed a greater number of physiological experiments than are ascribed to Harvey, and, perhaps, as Payne suggests, his experimental work was an indispensable preliminary to Harvey's.

We should note here that two of Harvey's contemporaries had preceded him in the introduction of experimental methods, though in another department of science. Galileo's experiments on the acceleration of falling bodies were made in 1590,[1] and as early as the year 1600 William Gilbert, "the father of electric and magnetic science," had published his *De Magnete,* with accounts of experiments with the loadstone and on the earth as a great magnet. The conception of the experimental method was both older than Harvey and entertained by others at the same time with him, but it was through his exertions and influence that the method became established in natural science during his life-

[1] The report on Galileo's experiments existed only in manuscript and although circulated was not published at the time. Also Peter Peregrinus of the thirteenth century has been shown to precede Gilbert in experiments with the magnet. (Thorndike.)

time, just at the close of the Renaissance and the opening of the modern epoch. The period in which Harvey lived was one of intense individualism. Vesalius had passed away in 1564, fourteen years before the birth of Harvey, but among the contemporaries of the latter were such brilliant individual thinkers as Galileo, Gilbert, Bacon and Descartes. It was these men who created the intellectual atmosphere of the day. The leadership was all in Italy, France and England; the German people, crushed and torn asunder by the ravages of the Thirty Years' War, were at this time intellectually, as well as materially, prostrate.

The rank of Francis Bacon in the history of science has been often discussed. By many writers he has been acclaimed as a man of profound influence on the progress of science, and even as the founder of inductive science itself. Usually, however, these claims have been put forward by writers of the literary type, and rarely have they had the support of scientific investigators. As a matter of fact, Bacon was not acknowledged by the select circle of contemporary scientists. Harvey was Bacon's personal physician and it is not out of place in this connection to state briefly his opinion as to Bacon's standing in Science. Aubrey, the contemporary biographer of Harvey, writes: "He had been physitian to the Lord Ch. Bacon, whom he esteemed much for his witt and style, but would not allow to be a great philosopher. Said he to me 'He writes philosophy like a Ld. Chancellor,' speaking in derision." In other words, Harvey with the unerring instinct of the doer in science, detected the hollowness of Bacon's too facile thinking, based as this was on no great body of investigation. Bacon, in the nature of the case, could not make any contributions to scientific knowledge in any way comparable to those of Galileo, Gilbert, and Harvey. He was rather a generalizing genius, a man celebrated for his "witt" who wrote a popular exposition of the method of advancing scientific knowledge. Singularly unappreciative of much of the best scientific work, in astronomy he rejected the Copernican system, in magnetism he adversely criticized Gilbert's treatise; "he was doubtful whether instruments were of any advantage, while

Galileo was investigating the heavens with the telescope. Ignorant himself of every branch of mathematics, he presumed that they were useless in science, only a few years before Newton achieved by their aid his immortal discoveries." [2] Whatever influence he may have had on the development of philosophy — which is another question — he did not "found the inductive method" in science and his pronouncements had little, if any, weight in directing the researches of scientific investigators.[3]

Harvey was a different type from Bacon, fitted both by native talent and by his training for the part he played in the intellectual awakening. He was born at Folkestone, on the south coast of England, in 1578, the son of a prosperous yeoman. The Harvey family was well esteemed, and the father of William was at one time the mayor of Folkestone. Young Harvey, after five years in the King's school at Canterbury, went to Cambridge, and in 1593, at the age of sixteen, entered Caius College. He had already shown a fondness for observations upon the organization of animals, but it is unlikely that he was able to cultivate this at the university. There his studies consisted mainly of Latin and Greek, with some training in debate and elementary instruction in the science of physics.

HARVEY

His Education. In 1597, at the age of nineteen, he was graduated with the baccalaureate degree, and the following year he turned his steps towards Italy in search of the best medical instruction that could be found at that time in all the world. He selected the great university of Padua as his place of sojourn, being attracted thither by the fame of some of its medical teachers. He was fortunate in receiving instruction in anatomy and physiology from Fabricius, one of the most learned and highly honored teachers in Italy. The fame of

[2] Draper, *The Intellectual Development of Europe.*

[3] Bacon's "program" (*Advancement of Learning, Novum Organum,* etc.) had, of course, a great influence on cultivated opinion, generally speaking, and in this way helped to further the cause of science. The formation of the Royal Society was partly due to his work.

this master of medicine (who, from his birthplace, is usually given the full name of Fabricius *ab Aquapendente*) was widespread and he was recognized as eminent in anatomy and surgery. A fast friendship sprang up between the young medical student and this ripe anatomist, the influence of which must have been very great in shaping the future work of Harvey.

Fabricius was already sixty-one years of age, and when Harvey came to Padua was perfecting his knowledge of the valves of the veins. The young student was taken fully into his confidence, and here was laid Harvey's first familiarity with the circulatory system, the knowledge of which he was destined so much to advance and amplify. But it was the stimulus of the master's friendship, rather than what he taught about circulation, that was of chief value to Harvey. The views of Fabricius in reference to the circulation of the blood were those of Galen, and his conception of the use of the valves of the veins was entirely wrong. The amphitheater (Fig. 44) in which Harvey listened to Fabricius is still standing at Padua and is of some interest in its primitive equipment. The students stood up and leaned over a rail to view the demonstrations and take notes.

At Padua young Harvey attracted notice as a student of originality and force, and seems to have been a favorite with the student body as well as with his teachers. His position in the university may be inferred from the fact that he belonged to one of the aristocratic student-organizations, and, further, was designated a "councilor" for the "nation" of England. The practice of having student councilors was then in vogue at Padua; the students comprising the council met for deliberations and very largely managed the university by their votes upon instructors and university measures.

It is a favorable comment upon the standards of professional education in Italy of his time that, after graduation at the university of Cambridge, he studied four or more years along scientific and medical lines to attain the degree of Doctor of Physic at Padua.

On leaving Padua in 1602, he returned to England and took

the examinations for the degree of M.D. from Cambridge, inasmuch as the medical degree from an English university advanced his prospects of receiving a position at home. He opened prac-

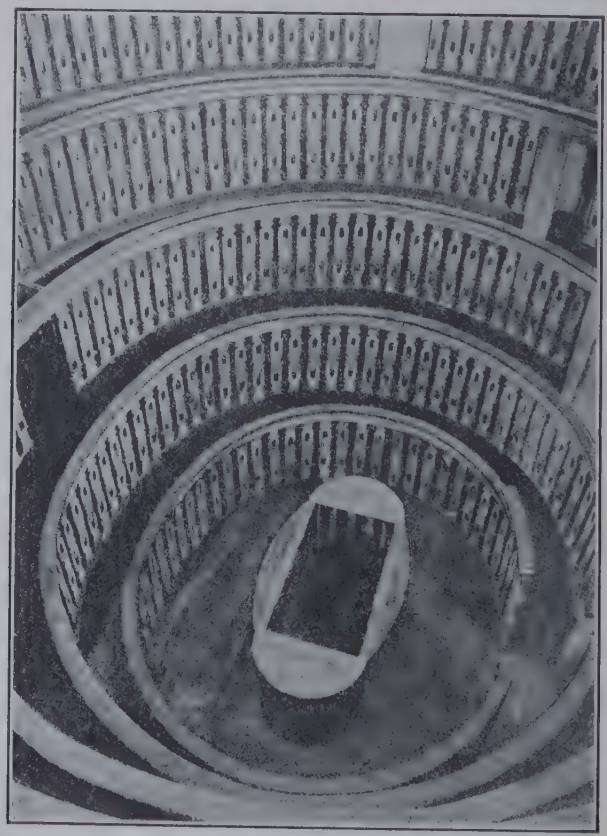

FIG. 44. — ANATOMICAL THEATER AT PADUA IN HARVEY'S TIME. (J. G. Curtis, *Harvey's Views on the Use of the Circulation of the Blood*, 1915.)

tice in London, was married in 1604, and the same year began to give public lectures on anatomy. By the year 1615 he was appointed lecturer at the Royal College of Physicians, and we have documentary evidence from lecture outlines written in his

own crabbed, almost illegible, hand that he was teaching the doctrine of the circulation of the blood as early as 1616. These notes were published in facsimile reproduction in 1886.

His Personality. Harvey had a marked individuality and seems to have produced a powerful impression upon those with whom he came in contact as one possessing unusual intellectual powers and independence of character. He inspired confidence, and it is significant that, in reference to the circulation of the blood, he won his associates in the medical profession over to his way of thinking. This is important testimony as to his personal power, since his ideas were opposed to the general belief of the time, and since on the continent they were vigorously assailed even after they had been accepted in England. Although described as choleric and hasty, he had also winning qualities, so that he retained warm friendships throughout his life, and was at all times held in high respect. It must be said also that in replies to his critics he showed great moderation.

The contemplative face of Harvey in his later years is shown in Fig. 45, taken from his picture in the National Portrait Gallery in London. It shows a countenance of composed intellectual strength with a suggestion, in the forehead and outline of the face, of some of the portraits of Shakespeare. An idea of his personal appearance may be had from the description of Aubrey, who says: " Harvey was not tall, but of the lowest stature; round faced, with a complexion like the wainscot; his eyes small, round, very black, and full of spirit; his hair black as a raven, but quite white twenty years before he died; rapid in utterance, choleric, given to gesture," etc.

He was less impetuous than Vesalius, who had published his work at twenty-eight; Harvey had demonstrated his ideas of the circulation in public " anatomies " and lectures for twelve years before publishing them, and when his great classic on the Movement of the Heart and the Blood first appeared in 1628, he was already fifty years of age.

His Publications. Harvey's publications were well thought out and matured before they were allowed to go to the printer.

Besides his masterpiece on the circulation of the blood, he published in 1651, at the age of seventy-three, a memorable treatise on embryology. But his publications do not fully represent his activity as an investigator; he tells in his *Generation of Animals* (Exercise 78) how through the fortunes of war he lost manu-

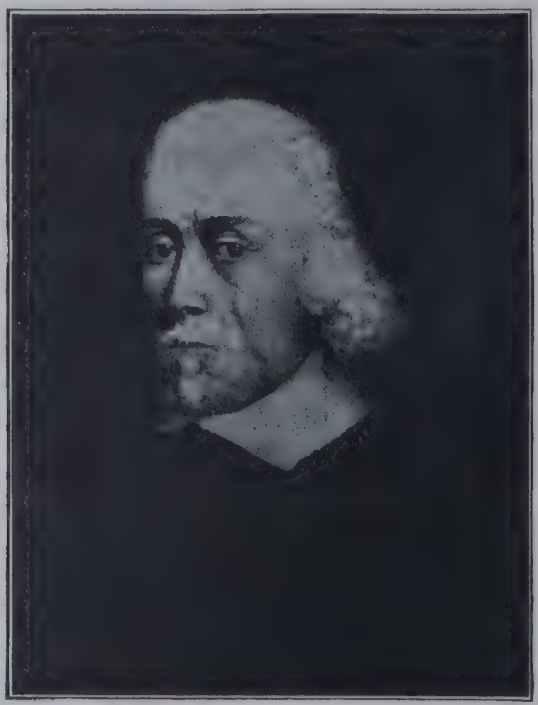

FIG. 45. — WILLIAM HARVEY, 1578–1657. (Moreton's *facsimile* edition of *De motu cordis et sanguinis.*)

scripts and drawings upon the comparative anatomy and development of insects and other animals. Attached to the Court as physician to Charles I, he followed that monarch through the changing fortunes of his contest with Parliament. During Harvey's absence his house at Whitehall was ransacked by military agents and personal "enemies" who carried away his furniture,

his museum and his papers; thus were lost, as Harvey says, "the fruits of many years of toil."

Harvey's observations on the movement of the heart were prolonged and searching; they were also broadly comparative. In his *De motu cordis et sanguinis* he mentions some forty animals upon which he had observed pulsations of the heart, including several invertebrates, as well as fishes, amphibia, reptiles, birds and mammals. In this work also he makes two distinct references to the use of magnifying glasses, showing that prior to 1628 he had employed lenses. In chapter four (p. 28) he says: "I have also observed that almost all animals have truly a heart, not only (as Aristotle says) the larger red-blooded creatures, but also the smaller pale-blooded crustacea and shell fish, such as slugs, snails, mussels, shrimps, crabs, crayfish and many others; nay, even in wasps, hornets and flies, with the aid of magnifying glasses (*perspicilli*), and at the upper part of what is called the tail, I have seen the heart pulsating myself, and have shown it to many others." Again, in chapter seventeen, he makes similiar mention of a magnifying glass.

It is also known from one of his letters, dated 1651, that in the presence of several colleagues he had made injections of warm water from the pulmonary artery through the lungs into the left ventricle. This early injection-experiment is of more than passing interest as having been made on the human body, the cadaver being that of a man who had been hanged.[4]

His Great Classic on Movement of the Heart and Blood. Since Harvey's book on the circulation of the blood is regarded as one of the greatest monuments along the highway of biological progress, it is time to take notice of it in particular. Although relatively small, it has a long title: *Exercitatio anatomica de motu cordis et sanguinis in animalibus,* which may be freely translated, "An Anatomical Dissertation on the Movement of the Heart and Blood in Animals." The book is usually spoken of under the shorter title, *De motu cordis et sanguinis.* Although the full title seems somewhat repellent, the book is interesting to

[4] F. J. Cole: *Studies in the History and Method of Science,* Vol. II, 1921.

the general reader. It is a clear, logical demonstration of the subject, proceeding with directness from one point to another until the culminating force of the argument grows complete and convincing. "The demonstration of the circulation is irresistible."

The book in its first edition (Frankfort, 1628) was a quarto volume of seventy-eight pages.[5] As stated above, Harvey had presented and demonstrated his views on circulation in lectures to medical students since 1616. In this book, however, he showed for the first time in print, that all the blood in the body moves in a circuit, and that the beating of the heart supplies the propelling force.

In order to discover the fact of circulation, it would seem that he must have known of the existence of capillaries connecting the arteries and veins. But he did not actually see the blood moving from arteries to veins and he had no sure knowledge of a capillary network. He understood clearly from his observations and experiments that all the blood passes from arteries to veins and moves in "a kind of circle"; still, he thought likely that it filters through the tissues in getting from one kind of vessel to the other. It was reserved for Malpighi, in 1660 (published 1661) to see, with the aid of lenses, the movement of the blood through the capillaries in the transparent parts of animal tissues.[6] "Harvey made their existence a logical necessity; Malpighi made it a histological certainty." (Fraser Harris.)

Harvey's demonstration of the movement of the blood in a circuit was a matter of cogent reasoning based on a study of the structure and movements of the heart, on experiments with ligatures to show the direction of the blood currents — towards the heart in veins and away from the heart in arteries — and on calculations of the quantity of blood passing through the heart.

[5] An interesting facsimile of the original edition, accompanied by an English translation, was printed privately in 1894, for Dr. Moreton, and published by him in Canterbury.

[6] See under Leeuwenhoek, p. 211. Leeuwenhoek's demonstration of blood currents in capillaries connecting arteries and veins was more complete, but Malpighi observed the capillaries earlier.

He observed the movement of the heart in detail, and showed that its contraction expels blood into the arteries and produces the pulse. Furthermore, he showed (and this is the central point of his reasoning) that the quantity of blood which leaves the left cavity of the heart in a given space of time makes necessary its return, since in a half-hour (or less) the heart, by successive pulsations, throws into the great artery more than the total quantity of blood in the body. It has been commonly maintained (as by Whewell) that Harvey deduced the circulation from observations of the valves in the veins, but his quantitative determination of the blood passing through the heart is his crucial point.

His Argument. The gist of Harvey's argument is indicated in the following propositions: (I) The heart passively dilates and actively contracts; (II) the auricles contract before the ventricles do; (III) the contraction of the auricles forces the blood into the ventricles; (IV) the arteries have no "pulsific power," *i.e.,* they dilate passively, since the pulsation of the arteries is nothing else than the impulse of the blood within them; (V) the heart is the organ of propulsion of the blood; (VI) in passing from the right ventricle to the left auricle the blood transudes through the parenchyma of the lungs; (VII) the quantity and rate of passage of the blood peripherally from the heart makes it a physical necessity that most of the blood return to the heart; (VIII) the blood does return to the heart by way of the veins.[7] It will be noticed that proposition VII is the important one; in it is involved the idea of applying measurement to a physiological process.

Question as to Harvey's Originality. The question of how near some of his predecessors came to anticipating his demonstration of the circulation has been much debated. It often has been maintained that Servetus and Realdus Columbus held the conception of the circulation for which Harvey has become so celebrated. Of the various accounts of the views of Harvey's predecessors, those of Willis, Huxley, and Michael Foster are amongst

[7] Quoted with modifications from Hall's Textbook of Physiology.

the more judicial; that of Foster contains ample quotations from the original sources. The discussion is too long to enter into fully here, but a brief outline is necessary to understand what he accomplished, and to put his discovery in the proper light.

Galen's view of the movement of the blood was not completely replaced until the establishment of Harvey's view. The Greek anatomist thought that there was an ebb and flow of blood within both veins and arteries throughout the system. The left side of the heart was supposed to contain blood vitalized by a mixture of animal spirits within the lungs. The veins were thought to contain crude blood. He supposed, further, that there was a communication between the right and left side of the heart through very minute pores in the septum, and that some blood from the right side passed through the pores into the left side and there became charged with animal spirits. It should be pointed out that Galen also believed in the transference of some blood through the lungs from the right to the left side of the heart, and in this he foreshadowed the views which were later developed by Servetus and Realdus Columbus.

The notable work of Leonardo da Vinci as an anatomist has already been referred to (p. 161). He left in manuscript many notes and drawings of the heart and the blood vessels, and the recent analysis of his researches [8] brings out the fact that "Leonardo came very near to the conception of the circulation of the blood." He studied the movement of the living heart in pigs; he gave great attention to the ramifications of blood vessels and said of the aorta that it "subdivides into as many principal branches as there are principal parts to be nourished, branches which continue to ramify *ad infinitum*." His comments on the heart and circulation are distributed over many years and appear in several of his manuscripts, but nowhere has he given any clear description of the circulation; at times, however, he is so suggestive that he should rank with the other forerunners of Harvey.

[8] H. Hopstock, *Leonardo As Anatomist. Studies in the History and Method of Science*, Vol. II, p. 151.

Vesalius, in the first edition of his *Fabrica* (1543), expressed doubt as to the existence of pores in the partition-wall of the heart through which blood could pass; and in the second edition (1555) he became even more skeptical. In taking this position he attacked a fundamental part of the belief of Galen. The careful studies of Vesalius must have led him very near to an

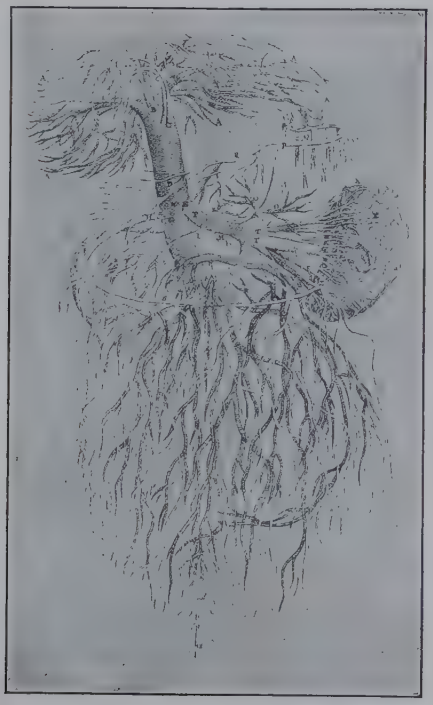

FIG. 46. — SKETCH OF THE PORTAL CIRCULATION ACCORDING TO VESALIUS.

understanding of the connection between arteries and veins. Fig. 46 shows one of his sketches of the arrangement of arteries and veins. He sketches the minute terminals of arteries and veins as coming very close together in the tissues of the body, but he did not grasp the meaning of the observation, because his

physiology was still that of Galen; Vesalius continued to believe that the arteries contained blood mixed with spirits, and the veins crude blood, and his idea of the movement was that of an ebb and flow. In reference to the anatomy of the blood-vessels, he goes so far as to say of the portal vein and the vena cava in the liver that " the extreme ramifications of these veins inosculate with each other, and in many places appear to unite and be continuous." All who followed him had the advantage of his drawings showing the parallel arrangement of arteries and veins, and their close approximation in their minute terminal twigs, but no one before Harvey had fully grasped the idea of the movement of the blood in a complete circuit.

Servetus, in his work on the restoration of Christianity (*Restitutio christianismi,* 1553), the work for which Calvin had him burned at the stake, expressed more clearly than Galen had done the idea of a circuit of blood through the lungs. According to his view, some of the blood takes this course, while he still admits that a part of it may exude through the ventricle from the right to the left side. This theological treatise would have been widely read at that period, but nearly all the copies were burned with the author and the views expressed had little direct influence in bringing about an understanding of the circulation. Nevertheless, there is some reason to think that it may have been the original source of the ideas of the anatomist Columbus, as Foster's studies of that observer seem to indicate.

Realdus Columbus, (to use the Latin form), once the disloyal deputy of Vesalius, later professor of anatomy at Pisa and, finally at Rome, expressed a conception almost identical with that of Servetus, and as this was in an important work on anatomy (*De re anatomica*, published in 1559) and well known to the medical men of the period, it lay in the direct line of anatomical thought and had greater influence. Foster suggests that the devious methods of Columbus, and his unblushing theft of intellectual property from other sources, give ground for the suspicion that he had appropriated this idea from Servetus without acknowledgment. Although Calvin supposed that the complete edition of

the work of Servetus had been burned with its author in 1553, a few copies escaped, and possibly one of these had been examined by Columbus. This presumption is strengthened by the circumstance that Columbus gives no record of observations, but almost exactly repeats the words of Servetus, and does not draw the conclusions that one would expect from an original observer who had worked out the conception of the circulation.

Cesalpino, the botanist and medical man, expressed in 1571 and 1593 similar views of the movement of the blood (probably as a matter of argument — to which he was much addicted — and since there is no record of either observations or experiments by him). However, he laid hold of a still more important conception, *viz.*, that some of the blood passes from the left side of the heart through the arteries of the body, and returns to the right side of the heart by the veins.

A fair consideration of the claims of each of these men to be called the discoverer of the circulation of the blood would require citations from their works and a critical examination of the evidence thus adduced. This has been excellently done by Sir Michael Foster in his *Lectures on the History of Physiology*. Fuller consideration of this aspect of the question exceeds the limits of our space. But we may say here that before Harvey, the circuit through the lungs had been surmised by Galen, Servetus, Columbus, and Cesalpino, and the latter had supposed some blood to pass from the heart by the arteries and to return to it by the veins; but no one had arrived at an idea of a complete circulation of all the blood through the system, and no one had grasped the consequences involved in such a conception. Harvey's idea of the movement of the heart (*De motu cordis*) was new; his notion of the circulation (*et sanguinis*) was new; and his method of demonstrating these was new. On the old idea of " secrete " pores in the septum between the two ventricles which retarded recognition of the route of blood from the right to the left side of the heart, Harvey is very emphatic. In his Introduction (p. 18) he writes: " But, by *Hercules,* no such pores can be demonstrated, nor in fact do any such exist. For

the septum of the heart is of a denser and more compact structure than any portion of the body, except the bones and sinews."

His Influence. Harvey was a versatile student. He was a comparative anatomist as well as physiologist and embryologist; he investigated the anatomy of about sixty animals and the embryology of insects as well as of vertebrates, and, best of all, he revived the experimental methods of Galen and made them current in biological investigation. Chemistry and histology were not sufficiently developed for Harvey to grasp the principles of nutrition, the feeding of the tissues, and the nature of respiration, but his letters show that he thought about these matters, and as time went on, he was inclined more and more to think of the heart merely as a pump and to emphasize the importance of the blood as a physiological factor.

His work on the movement of the blood was more than a record of a series of careful investigations; it was a landmark of progress. When we reflect on the part played in the body by the blood, we readily see that a correct idea of how it carries nourishment to the tissues, and how it brings away from them the products of disintegrated protoplasm is of prime importance in physiology. It is the point from which spring all other ideas of the activity of tissues, and until this was known no fine analysis of vital processes could be made. The true idea of respiration, of gland secretion, of chemical changes in the tissues, in fact, of all the general activities of the body, hinge upon this conception of the circulation of the blood. It was these consequences of his demonstration, rather than the bare fact demonstrated, which made it so important. The discovery did nothing less than create the possibility of a science of physiology, and as physiology is now an important branch of general biology, it is easy to see why Harvey's work is considered so important in the history of biology.

Those who wish to examine Harvey's views at first hand without having to translate them from the Latin, will find an edition of his complete works translated into English by Willis, and published by the Royal Society of London. The facsimile re-

production by Dr. Moreton of the first edition of the *De motu cordis et sanguinis,* with English translation is most interesting; there is also a cheap edition in *Everyman's Library.*

As is always the case when new truths are brought to light, there was strong hostility expressed to accepting Harvey's views. In England this hostility was slight on account of Harvey's great personal influence, but on the Continent there was many a sharp criticism passed upon his work, that of the pedantic Riolan of Paris being the best known. But, as Garrison says: " The discovery of the circulation itself was the most momentous event in medical history since Galen's time." Harvey's views were so illuminating that they were certain of triumph. During his lifetime they were generally accepted. His new conception of vital activities, together with his method of inquiry, became permanent parts of biological science.

CHAPTER XI

PRIMITIVE MICROSCOPES AND THE DISCOVERY OF MICRO-ORGANISMS

Primitive microscopes and pioneer observations with these instruments are of unusual interest; they represent the tools employed and the beginnings of a new kind of scientific knowledge. The question of who first constructed the microscope, however, is not one of great importance. The story is somewhat involved. But the period in which magnifying-glasses were brought into general use for the study of nature is well established as at the close of the sixteenth and in the first part of the seventeenth century. Nothing of this kind comes down to us from antiquity. We should like to believe that Aristotle, the Alexandrians, and Galen had means of increasing their natural vision, but no such evidence exists, though the unexpected discovery of so many appliances of antiquity has placed the modern mind in a receptive condition to all sorts of suggestions regarding the equipment of the ancients.

A lens-shaped rock crystal, discovered by Layard in the ruins of the palace at Nineveh, has been heralded as a quartz lens of great antiquity. This antique ornament or jewel, dating from 721–705 B.C., is now in the British Museum, and, as Myall, Charles Singer, and others have pointed out, its surface is not ground smooth but is cut into small facets, which disperse the light, so that it cannot act as a lens. Moreover, this piece of quartz is not clear, but is clouded by dark bands. "From a number of sites of classical antiquity crystal balls have been recovered and these may or may not have been used as burning-glasses. The point is doubtful, but it is certain that they are not lenses in the usual sense of the word." (Singer.)

Burning-glasses were used in antiquity, but the fragmentary and usually dubious references to magnifications by ancient writers are not satisfying. The most often quoted statement is from Seneca's *Natural Questions* (63 A.D.) in which he says: "I may now add that every object much exceeds its natural size when seen through water. Letters however small and dim are comparatively large when seen through a glass globe filled with water." In this connection Seneca is attempting to explain why the rainbow appears so large, and the rest of the text shows that he is merely sustaining his hypothesis that objects seen through water appear enlarged; it cannot be understood as a direct reference to the magnifying properties of transparent curved objects. Possibly the finest work of the ancient gem-cutters required some means of magnification, but it is likely that a strong illumination of the object would have been sufficient. Indeed, some modern gem-cutters testify that lenses were not necessary for the most minute work of the ancients and that the work could have been done even better without the intervention of a lens. At any rate, there is no evidence that magnifying appliances were employed in ancient times for observations of nature.

After a long lapse there begin to appear in the scientific writings of the Middle Ages references to the magnifying properties of lenses.[1] Alhazen, the Arabian physician, in a manuscript of 1052, not only discusses the human eye and optical principles, but also refers to sections of globules of glass or crystals as showing objects enlarged. Roger Bacon (1214–1294) in his *Opus majus* (1267) says that sections of globes of glass or crystal have been employed for magnification. His lenses were plano-convex. In the words of Singer, "Bacon accomplished a real advance in the knowledge of optics. . . . There is no evidence that he ever made a telescope nor any but a simple microscope, but he had an idea of the nature and property of lenses, and, groping with the instinct of genius, he did vaguely

[1] Charles Singer has recently worked out with great completeness the "Steps leading to the Invention of the First Optical Apparatus" — see his *Studies in the History and Method of Science*, Vol. II, 1921. I am greatly indebted to this article and to the earlier lectures of Myall on the microscope.

foresee both telescope and compound microscope." There is reliable evidence that spectacles as well as burning-glasses were in use in the early part of the thirteenth century.

THE EARLIEST MICROSCOPES

Passing now to the last part of the sixteenth century, we can trace more directly the manufacture and the use of magnifying lenses. There are various claimants for priority, but it is not clear to whom the credit belongs. There were a number of spectacle makers at that time in the Netherlands, Italy, Germany, etc., and it would seem that combinations of lenses inserted in the ends of tubes were "happened upon" independently by different parties. In these early days the development of telescopes and that of compound microscopes run parallel courses. The simple microscope, consisting of a single lens, appears to have been used before lenses in combination, but both kinds were often employed by the same observer. After recognizing the Englishman, Digges (1571), and the Hollander, Zacharias Jansen, about 1590, as prominent among the earliest inventors, we venture to say that to determine who actually was first, is a small matter compared with who first made the instrument the common property of science. For this honor perhaps Galileo has the best claim. He was, says Charles Singer, the "*effective*" inventor of the telescope and the compound microscope.[2] About 1608 he made his first telescope (soon followed by enlarged and improved forms); and with this combination of lenses he not only made observations on the celestial bodies, but also, in 1609, published microscopical observations on minute objects.

We know, as a matter of fact, that single lenses (and lenses in combination) had been used earlier and that the use of magnifying glasses for scientific purposes came about gradually.

[2] For a contrary statement see Article Galileo Galilei, by Agnes Mary Clarke, Ency. Brit., eleventh edition: "He did not become acquainted with the compound microscope until 1624 when he saw one of Drebbel's instruments in Rome." There is much confusion in the literature on this point, but Singer's statement is based on thorough investigation.

A considerable number of early works exist with pictures of insects, spiders, worms, etc., some of them showing enlargements. For illustration, George Hoefnagel published, in 1592, a set of fifty plates of insects engraved on copper. The pictures had been exquisitely drawn by his son, Jacob, at the age of seventeen, and some of them unmistakably indicate the use of magnifying glasses. So far as known, the pictures of Hoefnagel are the earliest printed figures of magnified objects. There is reason to believe, however, that the naturalist Mouffet had made an earlier use of magnifying lenses. His *Theater of Insects* (*Insectorum sive animalium minimorum theatrum*) was prepared in manuscript as early as 1590 but was not published until 1634. Some of the illustrations in this book show magnifications.

In the complicated question regarding the invention of microscopes, involving conflicting accounts, Charles Singer offers some deductions as follows: i. The invention of the microscope probably preceded that of the telescope. ii. The invention of the microscope was the work of Zacharias Jansen, after 1591 and before 1608. It was perhaps formed of two convex lenses. iii. This invention "was followed by that of the telescope, about 1608, by Lippershey and Metius." Its military application drew attention to it. iv. The first telescope was of the Galilean type with a concave eye-piece and convex objective. Galileo, however, made both the telescope and the microscope the property of science and was the *effective* discoverer of both. His instrument was improved by Kepler in 1611. The priority of effective demonstration of the telescope rests with Galileo and of the publication of a mathematical analysis with Kepler.

There is plenty of documentary evidence from writings in English, French, German, Dutch and Italian to establish the fact that the use of the simple microscope was common in the first half of the seventeenth century. By the time of Harvey magnifying glasses evidently were no novelty. As we have seen in his work on circulation of the blood published in 1628, he speaks in a matter of fact way in two places of his use of magnifying glasses.[3]

[3] For quotations see under Harvey, p. 187.

DESCARTES PICTURES

A few years later we have the earliest printed pictures of microscopes, when, in 1637, Descartes published his *Dioptrique* as an appendix to his well-known *Discourse on Method* and supplied two pictures with descriptions of microscopes. Figure 47 shows Descartes' picture of a simple lens provided with a means of illuminating the object to be examined. He represents the eye, in front of which at A, is a plano-convex lens inserted

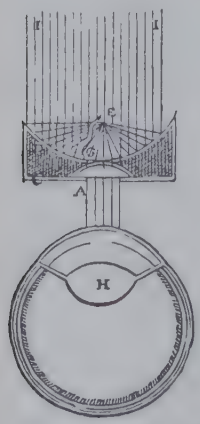

FIG. 47. — EARLIEST KNOWN PRINTED PICTURE OF THE SIMPLE MICROSCOPE, 1637. (Descartes, *Dioptrique.*)

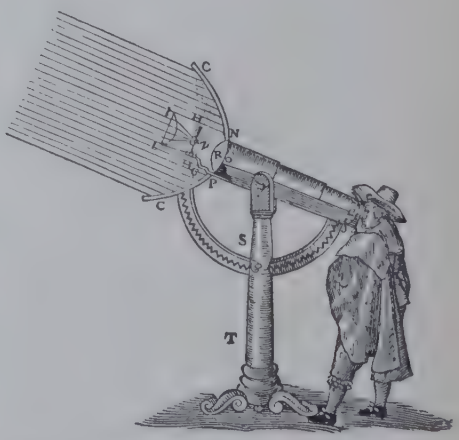

FIG. 48. — DESCARTES' REPRESENTATION OF AN "IDEAL MICROSCOPE," 1637. (Petri.)

in a blackened frame; behind the lens is a parabolic mirror with a transparent central area, through which the object can be viewed, the parallel rays of light from the mirror coming to a focus at the point E. The object to be examined is attached to an object-holder (G) at the point of greatest illumination.

In addition to the foregoing Descartes published a sketch of a huge, clumsy apparatus designated an "ideal microscope." As shown in Fig. 48 this had a sliding tube carrying a combination of lenses; the lens near the eye being plano-concave, and that at the far end of the tube (R) plano-convex. For illuminating the

object there was a concave mirror, similar to that of his simple microscope, and also a plano-convex lens placed in the pathway of light and giving a strong illumination at the point Z. Descartes says that the single lens may be replaced with one having two lenses combined. It is evident from these pictures and descriptions of Descartes that, in 1637, he had represented both the simple and the compound microscope. The large, unwieldly apparatus later was called, perhaps in derision, a "megaloscope," but so far as known it remained as a theoretical representation and was never manufactured.

ATHANASIUS KIRCHER

The pictures of Hoefnagel and Mouffet referred to above, were merely enlargements of objects visible to the unaided eye, but in the writings of Athanasius Kircher we have the first authenticated notices of microscopically minute living organisms. In his *Ars magna lucis et umbræ,* published in 1646, he describes a sphero-hyperbolic lens with which he made his first observations. Later he used an improved compound apparatus. He refers to the microscope of Descartes and describes his own. Speaking of the different kinds of microscopes known in his time, Kircher says that some use two convex lenses; others use large glass globes filled with water and still others use a new and clever discovery of the smallest glass globules not larger than the smallest pearl. With the aid of lenses of this nature Kircher saw minute "worms" in all decaying substances, in milk, and in the blood of persons stricken with fever.

In 1658, in his *Scrutinium pestis,* Kircher gave a notable anticipation of the germ theory of disease. He described living "corpuscula" as occurring in great number in the blood of plague-stricken persons and stated that these micro-organisms were the source of contagion. Kircher did not see the organisms that produce bubonic plague — which were discovered a long time afterward — the structures which he saw were probably pus-cells and rouleaux of blood corpuscles, but he did ascribe contagion to living organisms (*contagium animatum*). More than

one hundred years earlier "with remarkable clairvoyance," Fracastorius had attributed diseases to minute bodies or spores but he did not regard them as living organisms. Kircher's opinion was fortified by his observation of minute "vermicula" occurring in all putrefying substances and in the blood of the sick; his conclusion had some observational basis and his idea that infection is due to living organisms was a remarkable anticipation which has received merited attention in recent times. In following this idea of infection from living organisms, we note that about a hundred years later, in 1762, Plenciz believed that there was a particular organism (*seminarium*) for each disease with a definite incubation period, but this noteworthy example of prevision (together with others of similar import) was forgotten and was revived only in the nineteenth century.

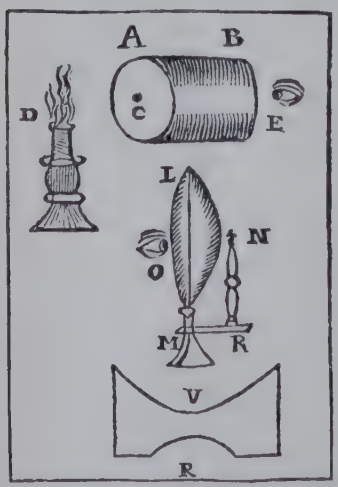

FIG. 49. — KIRCHER'S MICROSCOPE, 1646. (After Petri.)

We find a very interesting picture of Kircher's early microscopes, in his *Ars lucis et umbræ* of which Cut 49 is a reproduction. The instrument consisted of a short tube with a lens at one end and a plane glass at the other. Another picture of a similar contrivance (Figs. 49 & 50) shows ornamentation of the tube. The object to be examined was placed against the flat glass and the lens near the eye was the magnifier. This is the prototype of the simple microscope. Inasmuch as they were first used for magnifying insects these instruments came to be known as flea-glasses, and fly-glasses (*vitrea pulicaria, vitrea muscaria*, etc.). They were small tubes not thicker and longer than the thumb. In the last part of the seventeenth century they had quite a vogue as instruments of diversion, and we have documentary

evidence to show that in 1679 microscopes with spherical lenses (*microscopia globularia*) were on sale in Paris.

SIZE OF EARLY MICROSCOPES

In connection with Kircher we should mention Schott, his colleague and fellow member of the Society of Jesus. Kircher being occupied with another work besought his friend, Schott, to finish for him and publish a work on natural magic; this was done, and, in 1657, a year before Kircher's *Scrutinium pestis* appeared, Schott published with acknowledgments to Kircher a sort of preliminary volume designated *Magia optica*. The work

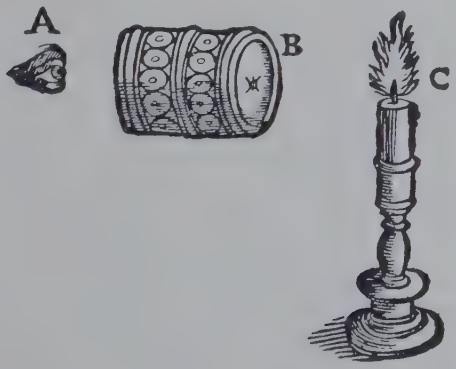

FIG. 50. — AN EARLY "FLEA-GLASS" WITH ORNAMENTATION OF THE TUBE. (Zahm, 1685.)

was translated and printed in German in 1671.[4] Fig. 51 is a photograph of the plate of microscopes in Schott's book. The size of these microscopes has been misconceived on account of the full-length human figure represented in connection with them, and it has been generally overlooked that the dimensions of the instruments are mentioned in the text. Schott says of A, that it is a small tube of wood or bone scarcely longer and thicker than a finger ("das kaum lenger und dicker ist als ein Finger Glaich"). At the end near the eye it is provided with a small

[4] I am indebted to Dr. A. B. Luckhardt of Chicago for the use of his copy.

spherical glass not larger than the smallest pearl. The other instruments represented are described as relatively small. The dimensions of D, the largest one, are given as having a tube a foot long and thicker than the thumb — mounted perpendicularly on a small block three feet high. These instruments were not huge "megaloscopes" as represented in Descartes' "ideal

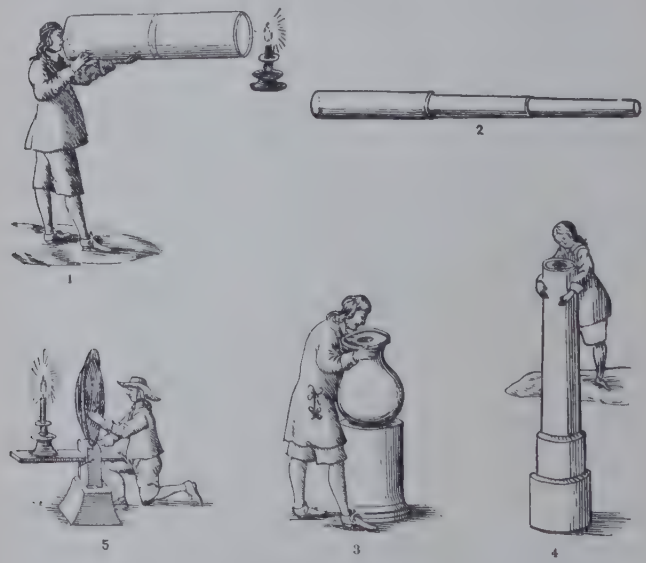

FIG. 51. — EARLY MICROSCOPES FROM SCHOTT'S *Magia optica*, GERMAN TRANSLATION, 1671. (Loaned by Dr. A. B. Luckhardt.)

microscope." The presumption is that the artist inserted an entire human figure in place of the single eye commonly shown in pictures of this nature.

In other early sources we have occasional mention of the size of the instruments employed. For illustration, Hooke's compound microscope (Fig. 52, about 1660) had a tube six or seven inches long. A picture supposed to represent the microscope of the Italian, Divini (about 1667), shows an instrument provided with five lenses, the length of which, by different writers, has been estimated from one foot to sixteen and one-half inches.

In 1665, Robert Hooke published his *Micrographia* — the first treatise devoted exclusively to microscopical observations. This book gave a real impetus to observations with the microscope, especially in England. Nehemiah Grew, the fellow countryman of Hooke, was stimulated by its publication to carry on his extensive observations on the microscopic structure of plants.

Psychological Influence. The psychological influence of the use of the microscope was very great. By sharpening attention and directing it towards definite points, the powers of mental application

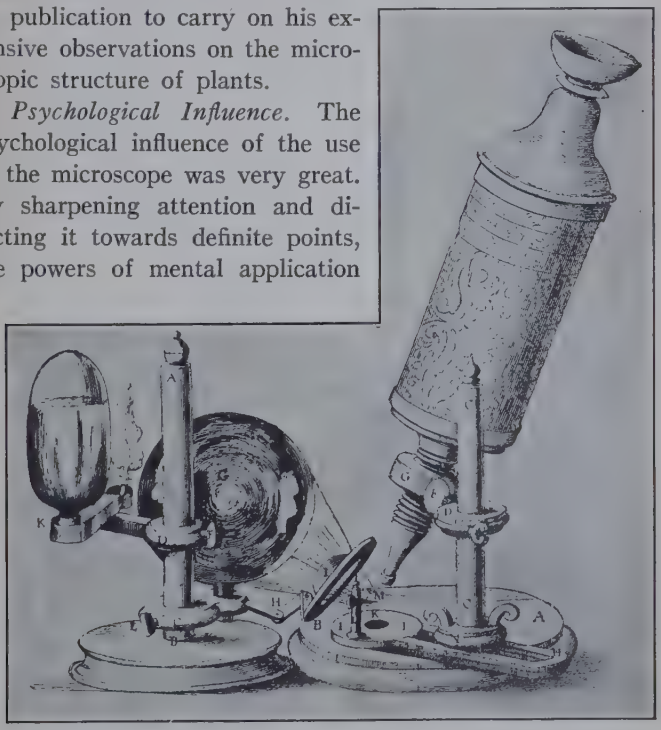

FIG. 52. — HOOKE'S COMPOUND MICROSCOPE, ABOUT 1660. (Carpenter, *The Microscope*.)

were improved and impressions received through the sense of sight were made more exact. Now perception through trained senses is the foundation of all scientific knowledge, and, as a matter of fact, we find the early workers with the microscope, Robert Hooke, Malpighi, Grew, and Leeuwen-

hoek, seeing nature more scientifically and exactly than their predecessors. As Sachs remarks in his *History of Botany:* " Perception by the use of the optic nerve had to be accompanied by conscious and intensive reflection, in order to make the object, which is observed only in part by the magnifying glass, clear to the mental eye in all the relation of the parts to one another and to the whole. Thus the eye armed with the microscope became itself a scientific instrument which no longer hurried lightly over the object, but was subjected to severe discipline by the mind of the observer and kept to methodical work." Although there was started a period of more incisive observation, the early microscopes were very imperfect and it was not until their improvement in the first third of the nineteenth century that the full effect of their use was realized.

THE DISCOVERY OF MICRO-ORGANISMS

In connection with the introduction of the microscope as a tool of science there naturally comes the discovery of micro-organisms, both animals and plants, and also the minute structure of tissues, of organic, and of mineral substances.

The first to devote a long life to studies with the microscope, and to make a large number of observations — sometimes illustrated with sketches — was the Dutch observer Antony van Leeuwenhoek of Delft. Through his multitudinous observations, published chiefly in the Transactions of the Royal Society of London and extending over a period of forty years, he made the microscopical world known to a wide circle. We may cluster about the name of Leeuwenhoek the story of early microscopical observations — remembering that there were other men who took part in the development of this kind of knowledge.[5]

Leeuwenhoek made his observations with small microscopes of his own contrivance. Although he made several hundred of

[5] In particular, Malpighi, the Italian, earlier in the field than Leeuwenhoek, extended his observations to the embryology of animals, to the minute structure of plants, to circulation of the blood in the transparent lungs of the frog (1660), etc., and Swammerdam, who used lenses extensively in investigating the structure of insects.

these instruments for his own use, he was not, as represented in Dr. Carpenter's article in the ninth edition of the *Encyclopædia Britannica,* an optician nor a manufacturer of lenses for the market. Prior to 1885, there was little known of the personal history of Leeuwenhoek, but, about that time, A. Wynter Blyth, by making researches in Leeuwenhoek's native town of Delft, brought to light many facts regarding his life and occupations.[6]

Van Leeuwenhoek was descended from a good Dutch family, some members of which had acquired wealth in the brewing industry. Apparently his schooling was limited, and brought to a close at the age of sixteen, when he went to Amsterdam to become bookkeeper and cashier in the clothing establishment of one of his relatives. After a few years he returned to Delft and married at the age of twenty-two. Six years after his marriage, he accepted, under the Court of Delft, a minor office entitled "Chamberlain of the Sheriff." The duties of the office were those of a beadle, and were set forth in his Commission — a document still extant. The requirements of the position were light, as was also the pay, which amounted to about £26 a year. Leeuwenhoek held this post for thirty-nine years, and the stipend was thereafter continued to him to the end of his life.

Being financially independent, Leeuwenhoek was able to follow his own inclinations and he engaged in microscopical observations with keen enjoyment. He seems to have been fascinated by the marvels of the microscopic world, but the extent and quality of his work lifted him above the level of the mere dilettante. Nevertheless, his lack of methodical training was a handicap, and showed in the rather desultory character of his work. His observations, "except that they lie in the domain of natural history, were disconnected and appear in no order of systematized study."

Leeuwenhoek gave descriptions and some drawings of his microscopes, and those in existence have been described and

[6] These were published by Dr. B. W. Richardson in Vol. 2 of *The Asclepiad* for 1885.

figured by different writers, so that we have a very good idea of his working equipment. He preferred the single lens, with a small glass of great curvature, giving a small field but clearer definition than the compound microscope of Hooke. He made different microscopes to suit his purposes, having a range of magnification from forty to two hundred seventy diameters. The number of microscopes accredited to him is rather overwhelming; it is said that he possessed not less than two hundred forty-seven complete microscopes, two of which were provided with double lenses (probably two separate single lenses) and one said to be a triplet. In addition to these he had one hundred seventy-two lenses set between plates of metal, giving a total of four hundred nineteen lenses; three were of quartz or rock crystal, the remainder were of glass. More than one-half of the lenses were mounted in silver; three were in gold.

Twenty-two years before his death, Leeuwenhoek designated twenty-six of his microscopes to go to the Royal Society of London on his death. His communication to the Royal Society was dated August 2, 1701, and since it throws light on the extent to which he prepared his own instruments, it will be in order to quote from it: "I have (says Leeuwenhoek) a small black cabinet, lacker'd and gilded, which has five little drawers in it, wherein are contained thirteen long and square tin boxes, covered with black leather. In each of these boxes are two ground microscopes, in all six and twenty; which I did grind myself and set in silver; and most of the silver was what I had extracted from minerals, and separated from the gold that was mixed with it; and an account of each glass goes along with them."

"This cabinet, with the aforesaid Microscopes, (which I shall make use of as long as I live), I have directed my only daughter to send to your Honors, as soon as I am dead, as a mark of my gratitude, and acknowledgment of the great honor which I have received from the Royal Society." [7]

Baker in his work *The Microscope Made Easy* (1742) men-

[7] Weld's History of the Royal Society, Vol. 1, p. 245.

tions having had these instruments away from the rooms of the Society for examination. He described them and figured some of them, but soon after they were lost track of and, unfortunately, these heirlooms to science have never been recovered. Inasmuch as Baker had these microscopes under observation his testimony as to the shape of the lenses is important. He says: "Several writers represent the glasses Mr. Leeuwenhoek made use of in his Microscopes to be little globules, or spheres of glass; which mistake most probably arises from their undertaking to describe what they had never seen; for, at the time I am writing this, the cabinet of Microscopes left by that famous man, at his death, to the *Royal Society* as a Legacy is standing upon my table; and I can assure the world that every one of the twenty-six microscopes, contained therein, is a double convex lens, and not a sphere or globule."

One of Leeuwenhoek's originals exists at the University of Utrecht, and at the request of the author, Professor H. F. Nierstrasz photographed this instrument natural size. Three views of his photographs are shown in Fig. 53. The instrument has two small copper plates, perforated by an orifice in which the small, nearly spherical, lens is inserted. The object-holder is represented in the lower right-hand figure as thrown to one side. By a vertical screw the object could be elevated or lowered, and by a transverse screw it could be brought near or removed farther from the lens and thus be brought into focus. In use (Fig. 54), the instrument was held close before the eye against the light, and the object was viewed by transmitted light. In some instances, however, the microscope was provided with a concave reflector (Fig. 55) similar to that used by Descartes, to illuminate the object by reflected light.

Figure 56 shows the way in which the microscope was arranged by Leeuwenhoek to examine the circulation of the blood in the transparent tail of a small fish or a tadpole. The animal was placed in water in a slender glass tube, and the latter was held in a metallic frame, to which a plate (marked D) was joined, carrying the magnifying glass. The latter is indicated

in the circle above the letter D, near the tail-fin of the animal. The eye of the observer was applied close to the lens which was brought into position and adjusted by means of screws.

Just when Leeuwenhoek began to use the microscope is not known, but he was forty-one years of age before his first publication of observations appeared, in 1673, in the Transactions

Fig. 53. — A Leeuwenhoek Microscope in the University of Utrecht. (Photographed by Professor H. F. Nierstrasz.)

of the Royal Society of London. He was already famous in his own country, and had been introduced to the Royal Society by De Graaf; in 1680, he was elected a Fellow of the Society. Leeuwenhoek wrote his communications in Dutch (explaining in a letter of 1676 that he knew no other language), and these were "English'd" before publication. His contributions amounted

to one hundred twenty-five, and numerous letters preserved in the letter-book of the Society bring his letters and papers combined up to the number of three hundred seventy-five. In addition to the observations published in London, he sent twenty-seven papers to the French Academy of Sciences, which were published in its memoirs, and in 1697, he was elected a corresponding member of the Paris Academy. From time to time, Leeuwenhoek's observations were collected and reprinted both in Dutch and in Latin (1679, 1685–1718; 1715–1722). Out of these numerous contributions we select only three for especial mention.

FIG. 54. — TO SHOW HOW THE LEEUWENHOEK MICROSCOPE WAS HELD. (Petri.)

The Protozoa. The single-celled animals, since 1845, called protozoa, have become of unusual interest to biologists, because in them the processes of life are reduced to their simplest expression. Also, some of them are disease-producing, and in connection with their study in recent times, there has arisen a special division of zoölogy called "protozoölogy." The credit for their discovery belongs to Leeuwenhoek. It is humanly interesting to read his original descriptions expressed in the archaic language of the period. The following quotation from a Dutch letter turned into English will serve to give the flavor of his writing:

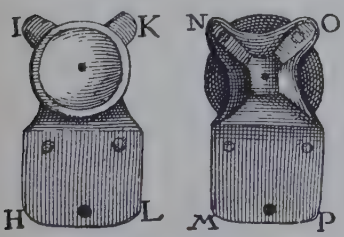

FIG. 55. — A LEEUWENHOEK MICROSCOPE PROVIDED WITH A CONCAVE REFLECTOR. (Petri.)

"In the year 1675, I discover'd living creatures in Rain water, which had stood but a few days in a new earthen pot, glazed blew within. This invited me to view the water with great attention, especially those little animals appearing to me ten thousand times less than those represented by Mons. Swam-

merdam, and by him called Water-fleas or Water-lice, which may be perceived in the water with the naked eye.

FIG. 56. — LEEUNWENHOEK'S ARRANGEMENT FOR VIEWING THE CIRCULATION OF THE BLOOD. (From his *Selected Works in English*, 1758.)

"The first sorte by me discover'd in the said water, I divers times observed to consist of 5, 6, 7, or 8 clear globuls, without being able to discern any film that held them together, or contained them. When these *animalcula* or living Atoms did move, they put forth two little horns, continually moving themselves. The place between these two horns was flat, though the rest of the body was roundish, sharpening a little towards the end, where they had a tayl, near four times the length of the whole body, of the thickness (by my Microscope) of a Spider-web; at the end of which appear'd a globul, of the bigness of one of those which made up the body; which tayl I could not perceive, even in very clear water, to be mov'd by them. These little creatures, if they chanced to light upon the least filament or string, of which there are many in water, especially after it has stood some days, they stook intangled therein, extending their body in a long round, and striving to dis-intangle their tayl; whereby it came to pass, that their whole body lept back towards the globul of the tayl, which then rolled together Serpent-like, and after the manner of Copper- or Iron-wire that having

been wound about a stick, and unwound again, retains those windings and turnings. This motion of extension and contraction continued a while; and I have seen several hundreds of these poor little creatures, within the space of a grain of gross sand, lye fast clustered together in a few filaments." [8]

Any one who has examined under the microscope the well-known bell-animalcule (*Vorticella*) will recognize in this first description of it the appearance of the stalk after contraction, under the designation of the " tayl " which retains those windings and turnings.

This paper of Leeuwenhoek embraces more than ten pages of observations, which indicates the diligence with which he had followed up his discovery. As to size, Leeuwenhoek says, that some of the animalcula in question are " more than 25 times less than a globul of blood."

Once started, observations of these minute organisms were carried forward by a number of English observers who also published their results in the Philosophical Transactions. These communications, however, were examples of miscellaneous observations, with the discovery of individual facts, and they did not have profound influence on progress. By the year 1693 pictures of the protozoa began to be published (pictures of the bacteria having been printed in 1683). Leeuwenhoek's first paper on the protozoa was not illustrated, but in 1703, he sent additional communications provided with sketches, and the same year he published the first known picture of Hydra.

At first, little distinction was made between micro-organisms, and protozoa, bacteria, hydra, rotifers, etc., were combined in a sort of *omnium gatherum*. In the eighteenth century, Linnæus, who did not use the microscope, and who uniformly misconceived the micro-organisms, placed them all together in a single group which he called " Chaos."

It was more than a hundred years (1786) after Leeuwenhoek's discovery when Otto Fr. Müller, the Dane, made a truly major contribution to the knowledge of micro-organisms. An

[8] *Philosophical Transactions*, Vol. XII, No. 133, March 25, 1677.

account of these advances is postponed until we have recorded some other advances of Leeuwenhoek.

Discovery of Bacteria. It is of especial interest that Leeuwenhoek observed and published sketches of organisms much more minute than the protozoa. In 1683, he discovered bacteria — which hold such a prominent place in present-day matters. This was a feat of trained observation and it is remarkable that Leeuwenhoek with his primitive equipment was able to see them and to describe them so clearly. One of his letters of 1681 indicates that he had seen bacteria at that time, but his formal description of them came in 1683. From his sketches and descriptions there can be no doubt that he saw the chief forms of bacteria — round, rod-shaped, and spiral forms.

His first observations on bacteria were communicated in a letter dated Sept. 17 (not 14), 1683, and published in the Philosophical Transactions for the year 1684. A photograph of the cut published with his observations is shown in Fig. 56A. The reproduction of the cut by Löffler, Petri, and others is not quite facsimile, and their quotations do not correspond verbally with the text in the Philosophical Transactions. Leeuwenhoek's Letters, however, were collected and published in Dutch and in Latin; Löffler used the Latin edition. A few lines from the original publication in the Philosophical Transactions show the objective quality of Leeuwenhoek's descriptions:

"Tho my Teeth are kept usually very clean, nevertheless when I view them with a Magnifying Glass, I find growing between them a little white matter as thick as wetted flower: in this substance tho I could not perceive any motion, I judge there might probably be living Creatures.

"I therefore took some of this flower and mixt it either with pure rain water wherein were no animals; or else with some of my Spittle (having no Air bubbles to cause a motion in it) and then to my great surprize perceived that the aforesaid matter contained very many small living Animals, which moved themselves very extravagantly. The biggest sort had the shape of A (see the Cut), their motion was strong and nimble, and they

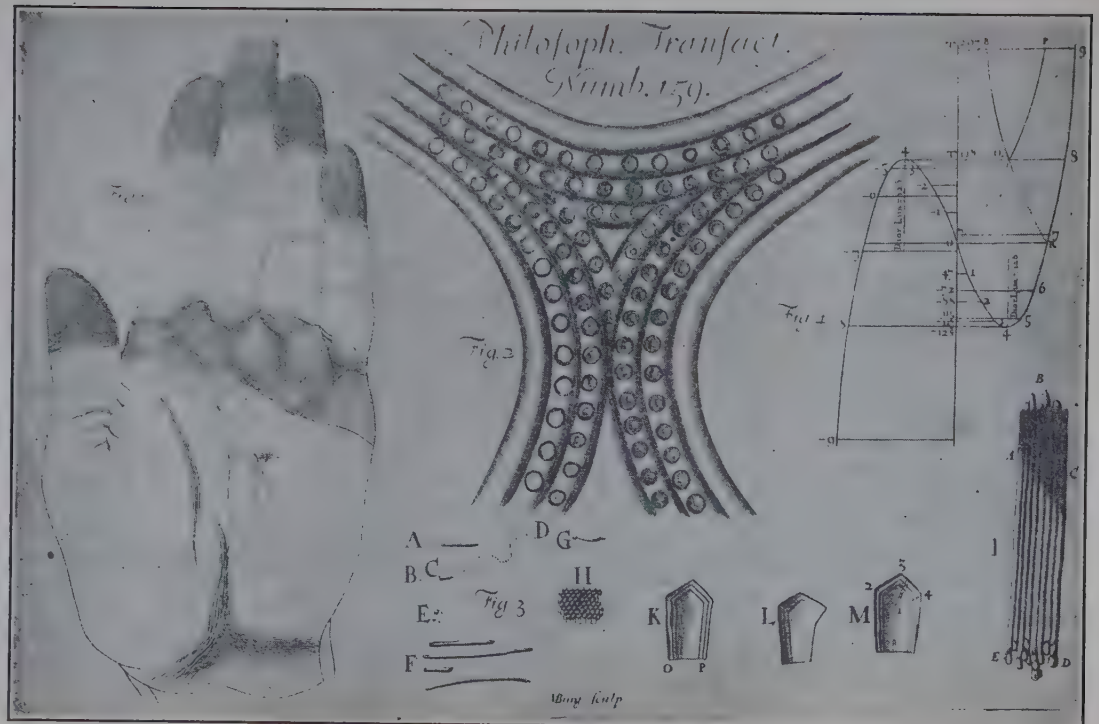

FIG. 56A. — PHOTOGRAPH OF THE ORIGINAL PLATE OF BACTERIA AS SEEN BY LEEUWENHOEK, 1683. (*Philosophical Transactions*, 1684, Chicago Public Library, H, scales of the "*cuticula*," not 1758).

darted themselves thro the water or spittle, as a Jack or Pike does thro the water. These were generally not many in number. The 2d. sort had the shape of B. these spun about like a top, and took a course sometimes on one side, as is shown at C and D. they were more in number than the first. In the 3d. sort I could not well distinguish the Figure, for sometimes it seem'd to be an Oval, and other times a Circle. These were so small that they seem'd no bigger than E. and therewithal so swift, that I can compare them to nothing better than a swarm of Flies or Gnats, flying and turning among one another in a small space. Of this sort I believe there might be many thousands in a quantity of water no bigger than a sand, tho the flower were but the 9th. part of the water or spittle containing it.

" Besides these Animals there were a great quantity of streaks or threds of different lengths, but like thickness, lying confusedly together, some bent, and some streight as at F. These had no motion or life in them, for I well observed them, having formerly seen live-Animals in water of the same figure."

Leeuwenhoek extended his observations to others: two women; a child of eight years; the spittle of an " old Man that had lived soberly " ; and another old man who was " a good fellow." The substance upon and between the teeth of the old men " had a great many living Creatures, swimming nimbler than I had hitherto seen. The biggest sort were numerous, and as they moved, bent themselves like G. The other sorts of Animals were in great numbers, insomuch that tho the meal were little, yet the water that it was mixt with seem'd to be all alive, there were also the long threads above mentioned." [9]

The figure marked H has very generally perplexed writers, and has been designated by some as a representation of those round bacteria which occur in packets of cubes (sarcinae), but later in the same paper Leeuwenhoek says that H represents scales of the outer skin (cuticula).

It is worthy of note that bacteria were pictured before protozoa and, if we except the picture of a shelled-protozoan (Ro-

[9] *Philosophical Transactions*, Vol. 14, No. 159, May 20, 1684.

talia) by Hooke, in 1665, they were, I believe, the first published pictures of micro-organisms.

Circulation of the Blood. Leeuwenhoek's ocular demonstration of circulation of the blood was very complete and was a notable contribution to physiology. It should be remembered that Harvey had not actually seen the circulation of the blood through capillaries. On entirely sufficient grounds he announced the existence of a complete circulation, but there was wanting in his demonstration the direct ocular proof of the passage of the blood from arteries to veins. In his efforts to get a clear view of the circulating blood he tried various animals; the comb of the young cock, the ears of white rabbits, the membraneous wing of the bat were progressively examined. The next advance came in 1688, when he directed his microscope on the transparent tail of the tadpole. Upon examining this he exclaims:

"A sight presented itself more delightful than any mine eyes had ever beheld; for here I discovered more than fifty circulations of the blood in different places, while the animal lay quiet in the water, and I could bring it before my microscope to my wish. For I saw that not only in many places the blood was conveyed through exceedingly minute vessels, from the middle of the tail toward the edges, but that each of the vessels had a curve or turning, and carried the blood back toward the middle of the tail, in order to be again conveyed to the heart. Hereby it plainly appeared to me that the blood-vessels which I now saw in the animal, and which bear the names of arteries and veins, are, in fact, one and the same; that is to say, that they are properly termed arteries so long as they convey the blood to the furtherest extremities of its vessels, and veins when they bring it back to the heart. And thus it appears that an artery and a vein are one and the same vessel prolonged or extended."

This description shows that he fully appreciated the course of the minute vascular circulation and the nature of the communication between arteries and veins. His sketch of the circulation in the tail of the eel, as he says, "drawn by a limner,"

is shown in Fig. 57. Later Leeuwenhoek extended his observations to the web of the frog's foot, the tail of young fishes and of eels. In this connection we should remember that Malpighi described the flow of blood in the lungs and in the mesentery of the frog in 1666, but he made little of the discovery. Leeuwenhoek did more with his, and gave a more clear and complete idea of the circulation.

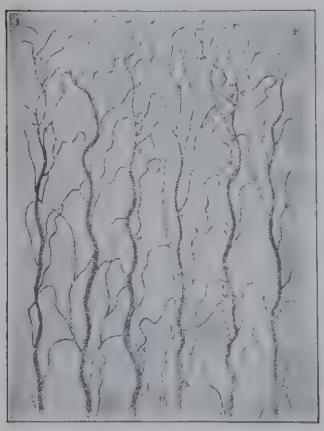

FIG. 57. — THE CAPILLARY CIRCULATION AS PICTURED BY LEEUWENHOEK, 1686.

The many other microscopical discoveries of Leeuwenhoek can not be dealt with in detail; his discovery of spermatozoa, however, in 1677, attracted wide attention and is of especial interest in the history of embryology. One consequence of the discovery of the hitherto unknown world of microscopic life was to reopen in a new form the question of the spontaneous origin of life. Although Redi, in 1668, by his experiments on the generation of insects, had disproved the spontaneous origin of organisms visible to the unaided eye, the question was now revived in reference to these microscopic "animalcula." Leeuwenhoek had discussed it and taken a position against spontaneous generation. Needham, Buffon, and, especially Spallanzani (1775), dealt with the question, and for a time it was set at rest by Spallanzani's experiments with the use of hermetically sealed flasks, but it arose again, and at intervals was a vexed question of biology until the convincing experiments of Pasteur and of Tyndall, in the nineteenth century.

PROGRESS OF KNOWLEDGE REGARDING PROTOZOA AND OTHER MICRO-ORGANISMS

On account of the unusual interest attached to protozoan studies at the present time, we shall add a brief outline of the advances after Leeuwenhoek. For a hundred years after their

FIG. 58. — FIRST PRINTED PICTURE OF THE AMŒBA, 1775. (Roesel's sketch in *Insecten Belustigungen*, Vol. 3, Pl. 101. John Crerar Library.)

discovery, the minute living organisms were observed, but their importance in physiology and in human affairs was not appreciated. A number of names of men prominent in the history

of science appear among these observers. Joblot, the Frenchman, Spallanzani, the Italian, who discovered the clear globular spaces now called pulsating vesicles, Réaumur, so notable for his observations on insects, and others, made individual discoveries. One of the most interesting sketches of the period is that of Rœsel von Rosenhof, the master of miniature illustration and the student of insects. In his 'Insect Diversions' (*Insecten Belustigungen*) in 1775, he published the earliest picture (Fig. 58) of the common amoeba — a primitive form of life now made generally known to the reading public, and so often examined in the laboratory by beginners in biology.

Otto Frederich Müller. The first marked advance came in 1786 through the publication of a mature and comprehensive work prepared by Otto Frederich Müller (1730–1784) and first printed two years after his death. This, the first standard treatise on micro-organisms, was entitled *Animalcula infusoria.* Its extent can be measured from the circumstance that it is a quarto volume of three hundred sixty-seven pages with fifty plates of sketches. The title is used in a broad sense; for the work includes bacteria and many other microscopic organisms, as well as "Infusoria." The suggestive term "Infusoria" had been introduced, in 1763, by Ledermüller to embrace those organisms found in infusions of hay, etc.

FIG. 50. — OTTO FR. MÜLLER, 1730–1784. (Hansen, *Illustrert Dansk Litteratur Historie*, 1902.)

The exact and searching quality of Müller's observations on microscopic organisms separates it from earlier work in the same field, and as he had pursued his investigations over a period of twenty years, he had published during his life several contributions to the subject. In the introduction to the posthumously published work of 1786, he gave a sharp and discriminating re-

view of earlier observations, pointing out that they were chiefly made in the spirit of uncritical wonder, that they lacked method and the making of clear and accurate distinctions between the forms studied, so that one could scarcely tell in a particular instance what forms had been observed. He remedied these defects. Nearly three hundred species are drawn from life with such accuracy that they can be recognized today. Following the

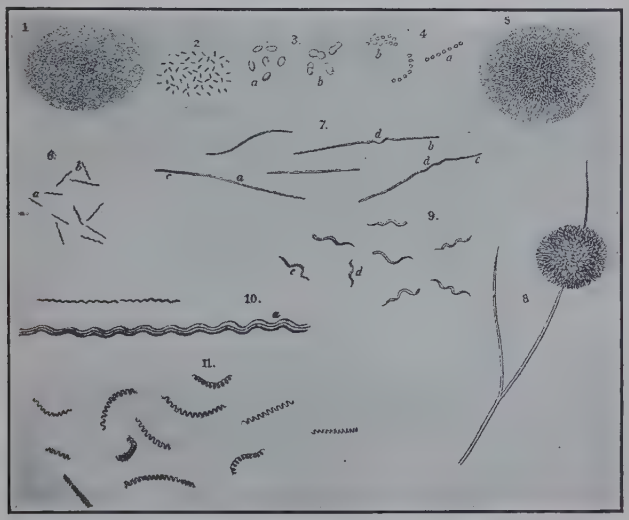

Fig. 60. — Micro-organisms from Müller's *Animalculæ infusoria*, 1786. (Löffler.)

binomial system of naming, which had been made current by Linnæus some years earlier, Müller supplied generic and specific names for his organisms and arranged them in systematic order. Of course, he included in his analysis of *Animalcula infusoria* the bacteria, as well as the protozoa, and other microscopic forms; the "Infusoria" as now understood occupying not more than a third of the treatise. Müller's work created a new basis for advance. An example of his pictures is shown in cut 60.

Ehrenberg. After Müller, observations on micro-organisms

went forward with increased impetus resulting in the accumulation of a large number of individual facts, but the next publication necessary to mention on account of its general influence is that of Ehrenberg (1795–1876). This scientific traveler and eminent observer was the author of several works. He was one of the early observers of nerve fibres and of other structures of the animal body. His treatise on micro-organisms is a beautifully illustrated monograph consisting of five hundred thirty-two pages of letter-press and sixty-nine plates, both text and plates being of folio size. It was published in 1838 under the German title *Die Infusions-thierchen als Vollkommene Organismen,* in English, "The Infusoria as Perfect Organisms." Besides the protozoa it includes many plant forms such as desmids, diatoms, bacteria, etc., and small multicellular animals such as rotifers. Some of the animalcula which he so faithfully represented in his sketches have the habit, when feeding, of taking into the body collections of food-particles, aggregated into spherical globules called food-vacuoles. These are distinctly separated and, while undergoing digestion, they slowly circulate within the single-celled body. In a fully fed animal these food-vacuoles occupy different positions, and, being enclosed in globular spaces within the protoplasm, they give an appearance which led Ehrenberg to conclude that these animals possess many stomachs. Accordingly, to the ciliated infusoria, in particular, he gave the name of "Polygastrica," and assigned to them a much higher grade of organization than they really possess. He declared that they have a muscular, a nervous, a circulatory, and a reproductive system comparable to that of the many-celled animals. His publication was almost simultaneous with the formulation of the cell-theory (1838–1839), the acceptance of which was destined to overthrow his conception of the infusoria, and to make it clear that tissues and organs (such as Ehrenberg postulated for the infusoria) can occur only in multicellular organisms.

Regardless of the bizarre conclusions of Ehrenberg regarding the nature of the infusoria, his observational work was of the

highest value, and his pictures, as regards form and general appearance of these animals, are both accurate and artistic.

Dujardin, whom we shall soon come to know as the scientific discoverer of protoplasm, successfully combatted (1841) the conclusions of Ehrenberg regarding the organization of the in-

Fig. 61. — Ehrenberg, 1795–1876.

fusoria. For a time the great German scientist tried to maintain his point that the infusoria have many stomachs, but this was completely swept away, and finally the contention of von Siebold (1845) was adopted to the effect that these animals are each composed of a single cell.

By the year 1857, von Stein, whose influence on progress was greater than that of Ehrenberg, was engaged in proposing names for the suborders of the ciliated infusoria based on the pattern of distribution of their cilia — a system which in its main features is still employed. Stein's monumental publications on the infusoria extended over several decades.

The numerous contributions to knowledge of nuclear and developmental phenomena must be omitted. Among others, however, the work of Claparède and Balbiani is especially important, and these men were the forerunners of the French school of protozoölogy later founded in Paris.

Importance of the Study of Micro-Organisms. In the period since 1880, investigations of the protozoa have assumed increasing prominence in physiology and in medicine. While it may seem invidious to mention only a few names, the researches of Richard Hertwig, Bütschli, Doeflein, and Fritz Schaudinn are of especial importance, and with the contributions of these, and other observers, we enter the current period of investigation.

Likewise the study of bacteria in their relations to human welfare, has assumed very great importance. As suggestive of major advances in this field we need only mention the names of Cohn, Pasteur, Koch and Lister.

In the history of biological science, the results of investigation of micro-organisms hold almost a unique position. Many interesting problems have arisen in connection with recent studies of them, and two large subdivisions of biology have resulted — protozoölogy and bacteriology.

All protozoans exhibit the phenomena of animal life in their simplest expression, and experiments on the different forms have been the means of revealing the true nature of some of the more complex physiological processes of higher animals. Some of the protozoa are disease-producing, such as the parasites of malaria, yellow fever and of the African sleeping sickness. Experiments of Maupas, Calkins, Woodruff, and others have a bearing on the discussions of immortality of the protozoans, — an idea which at one time was a feature of Weissman's theory of heredity. Binet, and others, have discussed the evidence of psychic-life in these micro-organisms, and the daily activity of some protozoans became the field of observation and record in an American laboratory of psychology. The extensive studies of Jennings on the nature of the responses of the lower organisms to stimulations form a basis for the discussions of animal behavior.

CHAPTER XII

THREE NATURALISTS OF THE SEVENTEENTH CENTURY

MALPIGHI, SWAMMERDAM AND LEEUWENHOEK

The preceding chapter dealt with a special aspect of biological advance — the introduction of the microscope and some results of its use. This was a splendid feature of the progress of natural history during the seventeenth century, but we should now mention some of the more general aspects of progress during that period, such as the stabilizing of the reform of scientific method, the beginning of scientific academies and the progress of independent investigation.

As Garrison says in his History of Medicine: "The seventeenth century was the age of individual scientific endeavor." The gains effected by Vesalius and Harvey might have receded except for strong followers filled with zeal for the new learning. Men of this type moved into and occupied the territory opened by the reformers; they defended the territory against the old form of theological assault, and in the end they consolidated the gains and established the domain.

This was "a time of spiritual and intellectual uplift": Shakespeare, Milton and Molière represent one phase of it in their writings of undying value; Bacon and Descartes in scientific philosophy, and a host of men in physical and natural sciences, such as Gilbert, Harvey, Galileo, Boyle, Borelli, and the great Newton. In natural history and medicine, we find such names as Malpighi, Swammerdam, Leeuwenhoek, de Graaf, Redi, Franciscus Sylvius, Tyson, Willis, Sydenham and others.

SCIENTIFIC ACADEMIES

Presently we shall select some men of natural history to represent the forward-looking movement, but first, we should speak of a new kind of coöperation in science which dates from the seventeenth century. This was the association of kindred spirits into Academies and societies and the periodical publications emanating from these associations. There were of course earlier academies of less specialized purpose, but here we refer only to the rise of scientific academies. These learned clubs, at least in England, were founded on a democratic spirit of fraternity; transcending the conventional lines of aristocracy as then conceived, they united "in the pursuit of truth men of different creeds, nationalities, vocations, and social ranks." As Libby says: "The history of science reveals men of all grades of intelligence and of all social ranks coöperating in the cause of human progress. It is a basis of intellectual and social homogeneity."

Although the men of the time were individualistic in their investigations, the advantages of coming together for conference, for communication of results and for discussion were evident. This stimulus widened the intellectual horizon of individuals and led to a more rapid dissemination of knowledge than had hitherto prevailed. Such associations began in Italy with the founding at Naples in 1560 of della Porta's Academy of the Secrets of Nature (*Academia Secretorum Naturæ*). This was followed, in 1603, by the Academy of the Lynx-eyed Associates (*Academia dei Lincei*). Galileo and Colonna were among its early members. It encountered opposition from the Church and was twice disbanded; finally, in 1870, it was resuscitated and "still survives, publishing handsome 'Transactions' in quarto." In 1657, the academy of experiments was established at Florence. In the meantime a similar movement was set on foot in England when Hartlieb, Boyle, Wren, Goddard, and others organized the "invisible college" (about 1645), which merged into the Royal Society of London. The latter body received a charter from

Charles II, in 1662, the king himself becoming a member. Doubtless Francis Bacon should receive the credit for planting the seed of the English society through his various writings towards the improvement of natural knowledge. There are several detailed histories of the Royal Society which should be consulted for the various steps and for the part taken by different men.

From the start, the "Royal Society for the Improvement of Natural Knowledge" was very active, and soon had in addition to its local members a number of foreign correspondents and Fellows. In 1665, it began the publication of its "world-renowned" Philosophical Transactions which continue today. To this English society de Graaf, Malpighi, Swammerdam and Leeuwenhoek sent results of their scientific investigations, those of Malpighi and Leeuwenhoek being especially numerous. These were published in the Philosophical Transactions, if not too long, and in some cases in separate volumes at the expense of the society as in the case of Malpighi's monographs: on the silkworm; on the anatomy of plants; on the formation of the chick in the hen's egg; and in the issue of his *Opera omnia.* Also in the seventeenth century the Royal Society published Hooke's *Micrographia,* 1665; Grew's *The Anatomy of Plants,* 1682; Willughby's *Historia piscium,* 1682; John Ray's *Historia plantarum,* two volumes, 1686–1688; Newton's famous *Principia,* 1687, etc. The Paris Académie des Sciences was founded in 1665 and began publishing its Histoires and Mémoires in 1669. We have seen in the previous chapter that Leeuwenhoek sent twenty-six of his scientific letters to the Paris academy, but by far a larger number to the Royal Society at London.

Societies of similar purpose were established in the last part of the seventeenth century in Germany and Denmark. But the rise of scientific academies is a large topic in itself and too extensive for our space so that here it cannot be followed further. It may be added, however, that these learned clubs of various countries numbered as members the leading men of science, and the history of their proceedings and transactions would embrace

nearly the whole story of the progress of science until the independent periodicals such as Annales, Archives, Journals, etc., became well established in the nineteenth century.

Returning now to individual investigators, it is well to keep in mind that there was concurrent progress in different lines of natural history, a sort of parallel development; although going forward simultaneously, for clearness these developments are considered separately. In the seventeenth century the general knowledge of animals and plants was much extended; not only the knowledge of local fauna and flora, but also, owing to frequent voyages and awakened curiosity, the natural history of distant lands came under consideration. Many exotic forms of life were brought to Western Europe, cabinets of natural history were multiplied, and exotic plants were cultivated in gardens. During the last part of the sixteenth and in the seventeenth century, extensive treatises on the history of animals and the history of plants were prepared and published, such as Gesner's famous *Historia animalium* and John Ray's *Historia plantarum,* with an occasional more special treatise such as the History of Fishes by Willughby and Ray. Publications of this type were based on excursions into the domain of natural history broadly considered, having chiefly in mind, form, general appearance, geographical distribution and habits of organisms, sometimes accompanied by anecdotes and reference to medical properties.

There was also arising a newer form of study of animals and plants — that of their structure and development, and to a certain extent, their physiology. Malpighi, for one, was devoted to this kind of investigation, and he did little in the way of natural history in the sense spoken of above. In the rest of this chapter we shall deal principally with this newer kind of investigation, reserving the story of natural history of the same period for subsequent consideration.

REPRESENTATIVE MEN

In structural studies, Malpighi, Swammerdam and Leeuwenhoek are representative of their century. Their individual contributions were numerous and may be taken to represent the newer kind of investigation which was going on in natural history. Their general influence may be summed up in the words of Richard Hertwig. Their great service to intellectual progress consisted chiefly in this — that, following the example of Vesalius and Harvey, " they broke away from the thraldom of mere book-learning, and relying alone upon their own eyes and their own judgment, won for man that which had been quite lost — the blessings of independent and unbiased observation."

Since the contributions of Malpighi, Swammerdam and Leeuwenhoek were such a distinctive feature of the natural history of the seventeenth century, we shall take each man separately for consideration.

MARCELLO MALPIGHI (1628–1694)

Malpighi was a typical scientific investigator; very different from the aggressive, almost truculent, Vesalius, and the testy Harvey, but possessing those generic qualities that mark the men of science — intellectual sincerity and a passion for research. A man's contribution to progress is essentially the product of his character and training, so that we find certain personalities about investigators are a part of scientific history, without being mere anecdotes and tales about the great and famous. Their temperament, education, circumstances under which they do their work, their aims and motives, all of these throw light on the results attained — this is the excuse for biographical facts in a history of science. Such facts, although always humanly interesting, are not given uniform consideration in the various chapters of this book, but occasionally occupy more space as a means of conveying an idea of the scientific mood.

Personal Qualities. There are several portraits of Malpighi extant. These, together with the account of his personal ap-

pearance given by Atti, one of his biographers, enable us to imagine what manner of man he was. The portrait shown in Fig. 62 is a copy of one painted by Tabor and presented by

Fig. 62. — Marcello Malpighi, 1628–1694. From a painting by Tabor (Pettigrew).

Malpighi to the Royal Society of London, in whose rooms it may still be seen. This shows him in the prime of life, with the

earnest, intellectual look of a man of high ideals and scholarly tastes, sweet-tempered, and endowed with the insight that belongs to a sympathetic nature. Some of his portraits, taken later, are less attractive, and the lines and wrinkles that show in his face give evidence of imperfect health. According to Atti, he was "of medium stature, with a brown skin, a delicate complexion, and a melancholy look."

Accounts of his life show that he was modest, quiet, and of a pacific disposition, notwithstanding that he lived in an atmosphere of acrimonious criticism, of jealousy and controversy. A family dispute in reference to the boundary-lines between his father's property and the adjoining land of the Sbaraglia family gave rise to a feud, in which members of the latter family followed him all his life with efforts to injure both his scientific reputation and his good name. Under all this he suffered acutely, and his removal from Bologna to Messina was partly to escape the harshness of his critics. Some of his best qualities showed under these persecutions; he was dignified under abuse and considerate in his replies. In reference to attacks on his scientific standing, there were published after his death replies to his critics that were written while he was smarting under their injustice and severity, but these replies are free from bitterness and are written in a spirit of great moderation.

Education. Malpighi was born at Crevalcuore, near Bologna, in 1628, the very year in which Harvey published his classic on movement of the heart and the blood. His parents were landed peasants, or farmers, enjoying an independence in financial matters. Since their resources permitted it, they designed to give Marcellus, their eldest child, the advantages of masters and schools. He began a life of study; and, before long, he showed a taste for belles-lettres and for philosophy, which he studied under Natali.

Through the death of both parents, in 1649, Malpighi found himself orphaned at the age of twenty-one, and since he was the eldest of eight children, the management of domestic affairs devolved upon him. He had as yet made no choice of a profession,

but through the advice of Natali, he resolved, in 1651, to study medicine, and, in 1653, at the age of twenty-five, he received from the University of Bologna the degree of Doctor of Medicine.

University Positions. Upon graduation, Malpighi became a candidate for a chair in the University of Bologna, but, owing to some opposition to his advanced views of medicine, he did not receive appointment until the year 1656, when as professor of medicine he entered enthusiastically upon his career as a teacher and investigator. He also kept up his practice of medicine. In the meantime, he had married the sister of Massari, one of his teachers in anatomy. This union was a very happy one, and although Francesca, his wife, " bore him no children, she stood by his side until a few weeks before his death, a tender cultivated help-mate." He must have shown aptitude for his work as a teacher, for he was soon called to the University of Pisa, where fortunately for his development, he became associated with Borelli, an older man experienced in investigations of physics, who assisted him in many ways. It should be said also that Malpighi turned the attention of Borelli to physiology. His true scientific career began in Pisa. Borelli and Malpighi united in some scientific work, and together they discovered the spiral character of the heart muscles as well as other facts. But the climate of Pisa did not agree with him, and after three years he returned again to teach in the University of Bologna, where he applied himself assiduously to investigations in minute anatomy.

Here his fame was in the ascendant, notwithstanding the machinations of his enemies and detractors, led by Sbaraglia. He was soon (1662) called to Messina to follow the famous Castelli. After a residence there of four years he again returned to Bologna, and as he was now thirty-eight years of age and devoted to investigation, he thought it time to remove to his villa near the city in order to allow himself more freedom to pursue his studies, but he continued his lectures in the university, and also his practice of medicine.

Honors at Home and Abroad. Malpighi's influence and at-

tainments were appreciated even at home. In 1686, the University of Bologna honored him with a Latin *eulogium;* the city erected a monument to his memory; and after his death in the city of Rome, his body was brought to Bologna and interred with great pomp and ceremony. At the two hundredth anniversary of his death, in 1894, a festival was held in Bologna, his monument was unveiled and a book of addresses by eminent anatomists of different countries was published in his honor.

During his lifetime he received recognition also from abroad, but that is less remarkable. In 1668 he was elected (honorary) Fellow of the Royal Society of London. He was very sensible of this honor; he kept in communication with the Society; he presented it with his portrait, and deposited in its archives, where they may still be examined, the original drawings illustrating the anatomy of the silkworm and the development of the chick.

In 1691, he was taken to Rome by the newly elected Pope, Innocent XII, as his personal physician, but under these new conditions he was not destined to live many years. He died there, in 1694, of apoplexy. Among his posthumous publications there is a sort of personal psychology written down to the year 1691, in which he recounts the growth of his mind, and tells the way in which he came to take up the different subjects of investigation.

Malpighi lived in a time when anatomy and physiology had not become separated into independent subjects of study. In addition to his practice of medicine he was microscopist, anatomist, botanist, embryologist, and to a certain degree naturalist, combined in one man — a type that went out about the close of the eighteenth century. He showed a leaning towards the physiological side, and in his studies of the minute structure of glands and tissues he was a pioneer physiologist. He was one of the early investigators of "physiological anatomy," and studied tissues with the microscope in order to elucidate their physiology.

His Researches. During forty years of his life he was al-

ways busy with research. Many of his discoveries had a practical bearing on the advance of anatomy and physiology as related to medicine. In 1660 (published 1661) he demonstrated the structure of the lungs. Previously these organs had been regarded as a sort of homogeneous parenchyma within which the blood and the air commingled. He showed the presence of air-cells, and had a tolerably correct view of how the air and the blood are brought together in the lungs, the two never actually in contact, but always separated by a membrane. The nature of his discoveries was first made clear to him in the lung of the frog, he having previously studied the lung of the dog without being able to interpret what he saw. Malpighi was comparative in his method and one of the first to insist on analogies between organs throughout the animal kingdom, and to make use of the idea that discoveries on simpler animals can be utilized in interpreting the corresponding structures in the higher ones. It is interesting to note that in connection with these observations he actually saw the passage of blood through the capillaries of the transparent wall of the frog's lung and also in the mesentery. At the same period Malpighi observed the blood corpuscles which, however, had been noted earlier (1658)[1] by Swammerdam.

Soon after the discoveries mentioned he demonstrated the mucous layer, or pigmentary layer of the skin, intermediate between the true and the scarf skin. He had separated this layer by boiling and maceration, and described it as a reticulated membrane. Even its existence was for a long time controverted, but it remains in modern anatomy under the title of the "Malpighian layer."

Malpighi's observations of glands were extensive, and while it must be confessed that many of his conclusions in reference to glandular structure were erroneous, he left his name connected with the Malpighian corpuscles of the kidney and of the spleen. He was also the first to indicate the nature of the papillæ on the tongue. The foregoing is a respectable list of discoveries

[1] There is, however, some uncertainty about this date, — see under Swammerdam.

that would entitle him to remembrance, but much more stands to his credit. Some particular examples of his monographic work will now be noticed; they represent a new kind of investigation and were the starting point of work in minute anatomy.

Malpighi as Pioneer Microscopist. Malpighi was a pioneer microscopist and probably antedated Hooke in the employment of the microscope for scientific observations. At any rate, five years before the publication of Hooke's *Micrographia* (1665), we know that Malpighi was using the microscope in his investigations. As previously recorded, Athanasius Kircher's *Ars magna lucis et umbræ* was published in 1646, containing descriptions of his microscopic observations. In point of time, Malpighi stands between Kircher and Hooke. The first definite record of Malpighi's use of the microscope with which I am acquainted is in 1660, though it is probable that he had used the instrument earlier. We have evidence from his scientific memoirs that he employed the microscope extensively in his studies of the structure of animal and vegetable tissues; his observations were so important that he may be considered to be the first great microscopist and the founder of microscopic anatomy. Although he wrote little about his instruments and his methods, we have testimony in his own words that he used both simple lenses and lenses in combination. In a letter to Borelli, referring to observations made in 1660 on the vascularity of the lung of the frog, he says: "And this you will see exceedingly well if you examine it with a microscope of a single lens against the horizontal sun. Or you may adopt another method of seeing these things. You will place on a transparent plate the lung, illuminated from below by the light of a lamp conducted through a tube and you will bring to bear upon it a microscope of two lenses. In this way the vessels distributed in a ring-like fashion will be disclosed to you. By the same arrangement of the instrument and the light you will observe the movement of the blood in the vessels lying in the field of view." (Michael Foster's translation.)

Monograph on the Structure and Metamorphosis of the Silk-

worm. Malpighi's work on the structure of the silkworm takes rank among the most famous monographs on the anatomy of a single animal. Much skill was required to give to the world this picture of minute structure. The marvels of organic structure were being made known in the human body and in larger animals, but "no insect — hardly, indeed, any animal — had then been carefully described, and all the methods of work had to be discovered." He labored with such enthusiasm in this new territory as to throw himself into a fever and to set up an inflammation in the eyes. "Nevertheless," says Malpighi, as quoted in Chapter I of this book, "in performing these researches so many marvels of nature were spread before my eyes that I experienced an internal pleasure that my pen could not describe."

He showed that the method of breathing was neither by lungs nor by gills, but through a system of air-tubes, communicating with the exterior through buttonhole-shaped openings, and, internally, by an infinitude of branches reaching to the minutest parts of the body. Malpighi showed an instinct for comparison; instead of confining his researches to the species in hand, he extended his observations to other insects, and has given sketches of the breathing-tubes, held open by their spiral thread, taken from several species.

The nervous system he found to be a central white cord with swellings in each ring of the body, from which nerves are given off to all organs and tissues. The nerve-cord, which is of course the central nervous system, he found located mainly on the ventral surface of the body but extending by a sort of collar of nervous matter around the oesophagus, and on the dorsal surface appearing as a more complex mass, or brain, from which nerves are given off to the eyes and other sense organs of the head. He misunderstood the "brain-mass" and on this point was soon corrected by Swammerdam. As illustrations of this monograph we have, in Fig. 67, reduced sketches of the nervous system and the food canal in the adult silkworm. The sketch at the right hand illustrates the central nervous cord with its ganglionic enlargement in each segment, the segments

being indicated by the rows of spiracles at the sides. The original drawing is on a much larger scale, and the reduction takes away some of its coarseness. All his drawings lack the finish and detail of Swammerdam's work.

He showed also the food canal and the tubules connected with the intestine, which retain his name in the insect anatomy

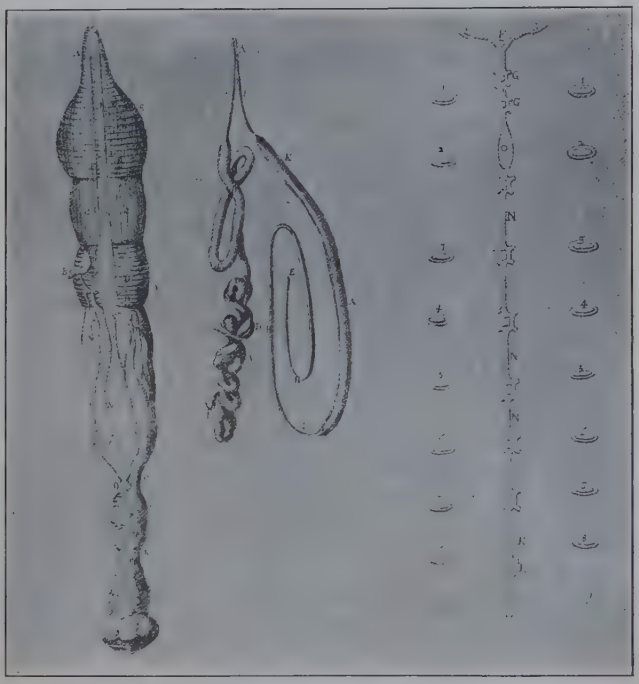

FIG. 63. — SKETCHES OF THE ANATOMY OF THE SILKWORM. (Malpighi, *Opera Omnia*, 1669.)

of today, under the designation "Malpighian tubules." The silk-forming apparatus was also figured and described. These structures are represented, as Malpighi drew them, on the left of Fig. 63.

The monograph, which was originally published in 1669

by the Royal Society of London, bears the Latin title *Dissertatio epistolica de bombyce*. It has been several times republished, the best edition being that in French, which dates from Montpellier, in 1878, and which is prefaced by an account of the life and labors of Malpighi.

Anatomy of Plants. Malpighi's anatomy of plants constitutes one of his best, as well as one of his most extensive works. In the quarto edition of his works, the *Anatome plantarum* (1675–1679) occupies no less than one hundred sixty-two pages and is illustrated by ninety-three plates of figures. It comprises an exposition of the structure of the bark, stem, roots, seeds, the process of germination, and includes a treatise on galls, etc.

In this work the microscopic structure of plants is amply illustrated, and he anticipates to a certain degree ideas on the cellular structure of plants. When he came to interpretations, he made several errors. Applying his often-asserted principle of analogies, he concluded that the vessels of plants are organs of respiration and of circulation, from a certain resemblance they bear to the breathing-tubes of insects. But his observations on structure are good, and if he had accomplished nothing more than this work on plants he would have a place in the history of botany. Sachs in his History of Botany gives Malpighi high place as one of the founders of vegetable histology, and says that he possessed greater genius and insight than Grew. He was also one of the first to discern the sexuality of plants and to give an account of the development of the seed and embryo.

Work in Embryology. Difficult as was his task in insect anatomy and in plant histology, a more difficult remains to be mentioned, *viz.*, his observations of the development of animals. He had pushed his researches into the finer structure of organisms, and now he attempted to answer this question: How does one of these organisms begin its life, and by what series of steps is its body built up? He turned to the chick, as the most available form in which to get an insight into this process, but he could not extend his observations successfully into periods earlier than about the twenty-four hour stage of development.

Two memoirs were written on this subject, both in 1672, which were published by the Royal Society of London under the titles, *De formatione pulli in ova* and *De ovo incubato*. Of all Malpighi's work, his observations in embryology have received least attention from reviewers, but for his time they represent a very remarkable achievement. No one can look over the ten folio plates without being impressed with the extent and accuracy of his observations. His sketches are of interest, not only to students of embryology, but also to the casual reader, to see how far observations regarding the steps in the development had progressed in 1672. Further consideration of Malpighi's position in embryology will be found in the chapter on the rise of that subject.

As Naturalist and Physiologist. Malpighi was a naturalist, but of a new type; he began to look below the surface, and essayed a deeper level of analysis in observing and describing the internal and the minute structure of animals and plants, and when he took the further step of investigating their development he was anticipating the work of the nineteenth century. Malpighi did not have, like Linnæus and Johannes Müller, a body of students and followers who owed to him their training and inspiration; he founded no school. He investigated a wide range of topics, but his "work in natural history produced no effect on his generation answerable to its real value." Miall thinks that his "extraordinary fertility really diminished his influence. Few workers received from him such practical training as enabled them to occupy the territories which he had discovered, and he became not so much a leader as a pioneer, who planted his standards so far ahead and so far apart that they could not serve as rallying-points, but merely as proofs that in several different directions he had outstripped all competitors."

We let a modern physiologist, Sir Michael Foster, speak of his attainments: "It may be truly said of Malpighi that whatever part of natural knowledge he touched he left his mark; he found paths crooked and he left them straight, he found darkness and he left light. Moreover in everything which he did

there is the note of the modern man. When we read Harvey we cannot but feel that in spite of all which he did, he in a way belonged to the ancients; while he was destroying Galen's doctrines he was wearing Galen's clothes, and speaking with Galen's voice. When we pass to Malpighi we seem to be entering into the ways and thoughts of today. Doubtless Malpighi was reaping what Harvey had sown; doubtless he was reaping also what Galileo had sown; doubtless also the microscope gave him a tool which none before him had possessed. It was just the putting these three things together which parts him from the old times, and makes him the beginning of the new.

"All the deeper problems of physiology turn on the mutual action of the tissues and the blood, as the stream of the latter sweeps among the elements of the former. Harvey showed that the blood did sweep through the tissues, Malpighi showed what the tissues were and how the blood swept through them. And thus the way was opened for those inquiries into the ways in which the blood acts on the tissue and the tissue acts on the blood, inquiries the results of which are the pride of modern times and the hope of times to come."

JAN SWAMMERDAM (1637–1680)

Swammerdam was a different type of man — nervous, incisive, very intense, stubborn, and self-willed. Much of his character shows in the portrait by Rembrandt represented in Fig. 64. Although its authenticity has been questioned, it is the only known portrait of Swammerdam.

Early Interest in Natural History. He was born in 1637, nine years after Malpighi. His father, an apothecary of Amsterdam, had a taste for collecting which was shared by many of his fellow-townsmen. The Dutch people of this time sent their ships to all parts of the world, and this vast commerce, together with their extensive colonial possessions, fostered the formation of private museums. The elder Swammerdam had the finest and most celebrated collection in all Amsterdam. This was stored, not only with treasures showing the civilization of remote

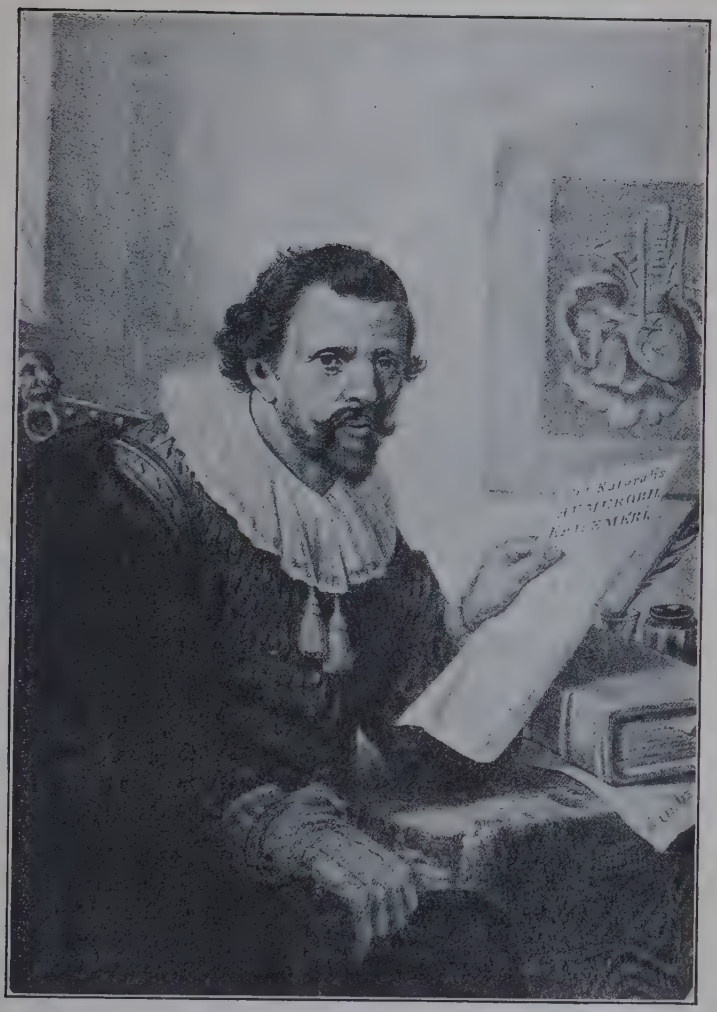

FIG. 64. — JAN SWAMMERDAM, 1637–1680. (From a painting by Rembrandt.)

countries, but also with specimens of natural history, for which he had a decided liking. Thus " from the earliest dawn of his understanding the young Swammerdam was surrounded by zoölogical specimens, and from the joint influence, doubtless of hereditary taste and early association, he became passionately devoted to the study of natural history."

Studies Medicine. His father intended him for the protestant ministry, but he had no taste for theology, though he became a fanatic in religious matters towards the close of his life; at this period, however, he could brook no restraint in word or action. He consented to study medicine, but for some reason he was twenty-six years of age before entering the University of Leyden. This delay was very likely owing to his precarious health, but, in the meantime, he had not been idle; he had devoted himself to observation and study with great ardor, and already had become an expert in minute dissection. When he went to the University of Leyden, therefore, he at once took high rank in anatomy. Anything demanding fine manipulation and dexterity was directly in his line.

At Leyden he had the stimulating influence of Franciscus Sylvius — a great teacher of medicine. Some of his associates were also helpful in his development. There he met the talented de Graaf, whose name is perpetuated in embryology through his discovery of the " Graafian " follicles of the ovary. This man was of such promise and attainments in anatomy that he was appointed the successor of Sylvius as professor in the university. De Graaf, however, lived only to reach the age of thirty-two, being cut off in the early part of his brilliant career. Swammerdam also met Stensen, the Dane, who is better known in anatomy under his Latinized name of Steno. " The year (1661) that Swammerdam matriculated, Steno, who was an advanced student in medicine, discovered the duct of the parotid gland " which still bears the name of " Steno's duct." In a few years Stensen forsook science for theology and became a Bishop of the Catholic Church and led a life of devoted service to the cause of religion. After his earlier studies at Leyden, and be-

fore receiving his degree, Swammerdam traveled "as was the rule with young students of adequate means." In this interval of travel he engaged in insect studies at the University of Saumur, visited Paris, and, finally, about 1667, received his degree of Doctor of Medicine from the University of Leyden.

During his period of medical study he made some rather important observations in human anatomy, and introduced the method of injection that afterward was ascribed to Ruysch. In 1664, he discovered the valves of lymphatic vessels by the use of slender glass tubes, and, three years later, first used a waxy material for injecting blood-vessels.

Regarding the date of Swammerdam's observation of the blood corpuscles there is some doubt. Miall has pointed out [2] that "The wrong date of 1658 is assigned to Swammerdam's discovery of the red blood-corpuscles of the frog by Foster, by Darmstädter, and probably by other writers. In 1658 Swammerdam had not begun his regular anatomical studies; he went to Leyden for this purpose in 1661. No date is assigned, so far as I know, either in the *Biblia naturæ* or in Boerhaave's Life pre-fixed thereto, to the discovery of the red corpuscles, but on page 839 of the *Biblia naturæ* the wrong date of 1658 is given to Swammerdam's demonstration of the muscle-nerve preparation before Cosmo III, Duke of Tuscany; it is well known that the Duke's visit took place in 1668. Swammerdam's observations on the red corpuscles of the frog cannot, therefore, it would seem, be dated at all." At all events, Swammerdam's observations were not published till fifty-seven years after his death, and since publication, not first observation, establishes priority, we may properly ascribe to Leeuwenhoek the first sure recognition of red corpuscles as elements of the blood.

Love of Minute Anatomy. After graduating in medicine he did not practice, but followed his strong inclination to devote himself to minute anatomy. This led to differences with his father, who insisted on his going into practice, but the self-willed stubbornness and firmness of the son now showed themselves.

[2] *The Early Naturalists*, p. 198.

It was to gratify no love of ease that Swammerdam thus held out against his father, but to be able to follow an irresistible leading toward minute anatomy. At last his father planned to stop supplies, in order to force him into the desired channel, but Swammerdam made efforts, without success, to sell his own personal collection and preserve his independence. Finally Swammerdam consented to yield to his father's wishes, and soon thereafter the father died, leaving him sufficient property to live on.

Boerhaave, his fellow-countryman, gathered Swammerdam's complete writings after his death and published them in 1737–1738 under the title *Biblia naturæ*. With them is included a life of Swammerdam, in which a graphic account is given of his phenomenal industry, his intense application, his methods and instruments. Many of the following passages are selected from that work.

Intensity as a Worker. He was a very intemperate worker, and in finishing his treatise on bees (1673) he broke himself down.

"It was an undertaking too great for the strongest constitution to be continually employed by day in making observations and almost as constantly engaged by night in recording them by drawings and suitable explanations. This being summer work, his daily labors began at six in the morning, when the sun afforded him light enough to enable him to survey such minute objects; and from that time till twelve he continued without interruption, all the while exposed in the open air to the scorching heat of the sun, bareheaded, for fear of interrupting the light, and his head in a manner dissolving into sweat under the irresistible ardors of that powerful luminary. And if he desisted at noon, it was only because the strength of his eyes was too much weakened by the extraordinary efflux of light and the use of microscopes to continue any longer upon such small objects.

"This fatigue our author submitted to for a whole month together, without any interruption, merely to examine, describe, and represent the intestines of bees, besides many months more

bestowed upon the other parts; during which time he spent whole days in making observations, as long as there was sufficient light to make any, and whole nights in registering his observations, till at last he brought his treatise on bees to the wished-for perfection."

Method of Work. "For dissecting very minute objects, he had a brass table made on purpose by that ingenious artist, Samuel Musschenbroek. To this table were fastened two brass arms, movable at pleasure to any part of it, and the upper portion of these arms was likewise so contrived as to be susceptible of a very slow vertical motion, by which means the operator could readily alter their height as he saw most convenient to his purpose. The office of one of these arms was to hold the little corpuscles, and that of the other to apply the microscope. His microscopes were of various sizes and curvatures, his microscopical glasses being of various diameters and focuses, and, from the least to the greatest, the best that could be procured, in regard to the exactness of the workmanship and the transparency of the substance.

"But the constructing of very fine scissors, and giving them an extreme sharpness, seems to have been his chief secret. These he made use of to cut very minute objects, because they dissected them equably, whereas knives and lancets, let them be ever so fine and sharp, are apt to disorder delicate substances. His knives, lancets, and styles were so fine that he could not see to sharpen them without the assistance of the microscope; but with them he could dissect the intestines of bees with the same accuracy and distinctness that others do those of large animals.

"He was particularly dexterous in the management of small tubes of glass no thicker than a bristle, drawn to a very fine point at one end, but thicker at the other." These were used for inflating hollow structures, and also for making fine injections. He dissolved the fat of insects in turpentine and carried on dissections under water.

An unbiased examination of his work will show that it is of a higher quality than Malpighi's in regard to critical observation

and richness of detail. He also worked with minuter objects and displayed a greater skill.

The Religious Devotee. The last part of his life was dimmed by fanaticism. He read the works of Antoinette Bourignon and fell under her influence; he began to subdue his warm and stubborn temper, and to give himself up to religious contemplation. She taught him to regard scientific research as worldly, and, following her advice, he gave up his passionate fondness for studying the works of the Creator, to devote himself to the love and adoration of that same Being. Always extreme and intense in everything he undertook, he likewise overdid this, and yielded himself to a sort of fanatical worship until the end of his life, in 1680. Had he possessed a more vigorous constitution he would have been greater as a man. He lived, in all, but forty-three years; the last six or seven years were unproductive because of his mental distractions, and before that, much of his time had been lost through sickness.

The Biblia Naturæ. It is time to ask, What, with all his talents and prodigious application, did he leave to science? This is best answered by an examination of the *Biblia naturæ,* under which title all his work was collected. His treatise on Bees and Mayflies and a few other articles were published during his lifetime, but a large part of his observations remained entirely unknown until they were published in this book fifty-seven years after his death. In the folio edition it embraces four hundred ten pages of text and fifty-three plates, replete with figures of original observations. It "contains about a dozen life-histories of insects worked out in more or less detail. Of these, the mayfly is the most famous; that on the honey-bee the most elaborate." The greater amount of his work was in structural entomology. It is known that he had a collection of about three thousand different species of insects, which for that period was a very large one. There is, however, a considerable amount of work on other animals: the fine anatomy of the snail, the structure of the clam, the squid; observations on the structure and development of the frog; observations on the contraction of the muscles,

etc. "Swammerdam proved experimentally that the stimulation of a nerve completely severed from the central nervous system may excite contraction in a muscle."

Swammerdam was extremely exact in all that he did. His descriptions are models of accuracy and completeness, and his sketches show a finish and detail not exceeded by those of any naturalist of the seventeenth century.

Fig. 65 shows reduced sketches of his illustrations of the structure of the snail. The upper sketch shows the central nervous system and the nerve trunks connected therewith, and the lower figure shows the shell and the principal muscles. This is an exceptionally good piece of anatomization for that time, and is a fair sample of the fidelity with which he worked out details in the structure of small animals. Besides showing this, these figures also serve the purpose of pointing out that Swammerdam's fine anatomical work was not confined to insects. His determinations on the structure of the young frog were equally noteworthy.

FIG. 65. — FROM SWAMMERDAM'S *Biblia naturæ*, 1737.

But we should have at least one illustration of his handling of insect anatomy to compare more directly with that of Malpighi, already given. Fig. 66 is a reduced sketch of the anatomy of the larva of an ephemerus, showing, besides other structures, the central nervous system in its natural position. When compared with the drawings of Malpighi, we see there is a more masterly hand at the task, and a more critical spirit back of the hand. The nervous system is very well done, and the greater detail in other features shows a disposition to go into the subject more deeply than Malpighi.

Besides working on the structure and life-histories of animals, Swammerdam showed, experimentally, the irritability of nerves and the response of muscles after their removal from the body. He not only illustrates this quite fully, but seems to have had a pretty good appreciation of the nature of the problem of the physiologist. He says:

"It is evident from the foregoing observations that a great number of things concur in the contraction of the muscles, and that one should be thoroughly acquainted with that wonderful machine, our body, and the elements with which we are surrounded, to describe exactly one single muscle and explain its action. On this occasion it would be necessary for us to consider the atmosphere, the nature of our food, the blood, the brain, marrow, and nerves, that most subtle matter which instantaneously flows to the fibers, and many other things, before we could expect to attain a sight of the perfect and certain truth."

In reference to the formation of animals within the egg, Swammerdam was, as Malpighi, a believer in the pre-formation theory. The basis for his position on this question will be set forth in the chapter on the Rise of Embryology.

There was another question in his time upon which philosophers and scientific men were divided, which was in reference to the origin of living organisms: Does lifeless matter, sometimes, when submitted to heat and moisture, spring into life? Did the mice of Egypt come, as the ancients believed, from the mud of the Nile, and do frogs and toads have a similar origin? Do insects

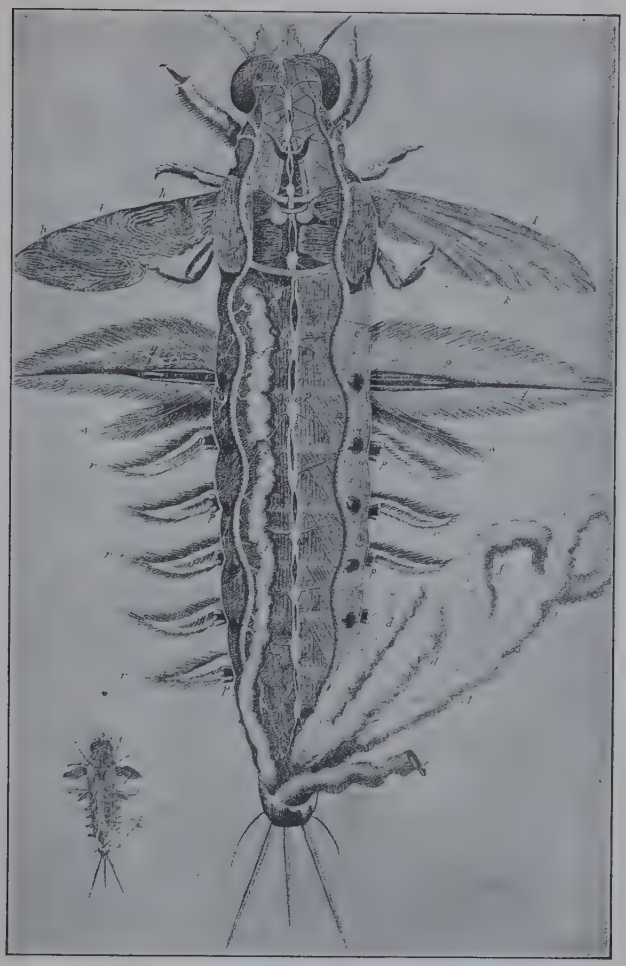

FIG. 66. — ANATOMY OF INSECT LARVA: DISSECTED AND DRAWN BY SWAMMERDAM.

spring from the dew on plants? etc., etc. The famous Redi performed his noteworthy experiments when Swammerdam was thirty years old, but opinion was divided upon the question as to the possible spontaneous origin of life, especially among the smaller animals. Upon this question Swammerdam took a positive stand; he ranged himself on the side of the more scientific naturalists against the spontaneous formation of life.

ANTONJ VAN LEEUWENHOEK (1632–1723)

In Leeuwenhoek we find a composed and better-balanced man. Blessed with a vigorous constitution, he lived ninety-one years, and worked almost to the end of his life. He was born at Delft, in 1632, four years after Malpighi, and five before Swammerdam; they were, then, strictly speaking, contemporaries. He stands in contrast with the other men in being self-taught; he did not have the advantages of a university training, and apparently never had a master in scientific study. This lack of systematic training shows in the desultory character of his prolonged and extensive observations. Impelled by the same gift of genius that drove his confrères to study nature with such unexampled devotion, he too followed the path of an independent and enthusiastic investigator. An account of his life and some of his microscopical observations has already been given; here we deal with certain other discoveries and with his general influence.

The portrait (Fig. 67) from a painting by Veekolje represents him holding one of his microscopes in his left hand. It was painted after he had passed the age of sixty years, and shows the pleasing countenance of a firm man in vigorous health. "In the face peering through the big wig there is the quiet force of Cromwell and the delicate disdain of Spinoza. It is a mixed racial type, Semitic and Teutonic, a Jewish-Saxon; obstinate and yet imaginative; its very obstinacy a virtue, saving it from flying too wild by its imagination." (Richardson.)

In the preceding chapter it has been related how Leeuwenhoek ground his own lenses and inserted them between metal plates; how in 1675, he discovered the protozoa; in 1677, the sperma-

tozoa; in 1683, the bacteria; and in 1686, observed the circulation of the blood in the transparent parts of several animals. These discoveries embrace his most important contributions to science, but in addition to these he left a great mass of miscel-

FIG. 67. — ANTONJ VAN LEEUWENHOEK, 1632–1723. (From a painting by Veekolje, done in 1685.)

laneous observations with the microscope. These observations were published in various forms: in his "Letters"; in the collections of his works entitled the "Secrets of Nature" (*Arcana*

naturæ); and in his *Opera Omnia*. These writings, published in the seventeenth and the first part of the eighteenth centuries, were in Dutch and in Latin — an English translation of selections from his "Microscopical Observations" was published also, by Samuel Hoole in 1798.

Among his observations not previously dwelt on, some especial interest attaches to his observations of red blood-corpuscles. The fair presumption is that Leeuwenhoek was the first to give an adequate account of the red blood-corpuscles. It is commonly stated that these elements of the blood were observed by Swammerdam in 1658, and by Malpighi in 1665, but there is a defect in these claims that needs to be cleared up. As stated above, under the topic "Swammerdam," the date of Swammerdam's observation of the red blood-corpuscles is doubtful, and so far as known the observations were not published until 1737–1738. Evidently Malpighi saw the red blood-corpuscles in 1665 but mistook them for fat globules. As translated from the Latin by Sir Michael Foster, Malpighi says: "And I myself in the omentum of the hedgehog in a blood vessel which ran from one collection of fat to another opposite to it, saw globules of fat, of a definite outline, reddish in color. They presented a likeness to a chaplet of red coral." Leeuwenhoek's descriptions are quite specific and comparative; "he shows that the mammals examined by him contained circular red corpuscles, the birds, amphibians and fishes oval ones." In the frog, and various fishes, he found them of flat and oval shape, and in fishes with "a luminous spot in the middle" — the nucleus. Those of the human body, however, he thought to be globular.

Other Discoveries. Although Leeuwenhoek did not pursue his studies methodically, he worked so long and on so many subjects, that he opened questions of great biological interest. Among his other discoveries bearing on physiology, medicine, histology and zoölogy we mention: — the generation of plant-lice (aphids) without fertilization and the presence of young within the body of the unfertilized female; the first observation of yeast-cells; the structure of the crystalline lens of the eye;

the structure of bone; the branched character of the heart muscles; the stripe of voluntary muscles; the microscopic structure of wood and other plants. He showed the color cochineal to be derived from the cochineal-insect, investigated the development of clams from eggs, etc.

He also discovered the Rotifers, those favorites of the amateur microscopists, made so familiar to the general public in works like Gosse's *Evenings at the Microscope*. He observed that when water containing these animalcules evaporates, they become reduced to fine dry dust, but retain their vitality, and become active again, even after great lapses of time, by being immersed in water.

His Theoretical Views. Leeuwenhoek's mind was more of the objective than of the subjective type, having a certain native shrewdness in discussing his observations, but he cannot be considered a great thinker. On two biological questions of the day he took a decisive stand. He was one of the early strong adherents of the belief that the embryo is pre-formed or predelineated in the sperm. In fancy, he saw under his microscopes the complete outline of both maternal and paternal individuals in the microscopic spermatozoa, and, indeed, went so far as to publish sketches of the same. On the question of the spontaneous generation of life, however, he took the side that has been supported with such triumphant demonstration in the nineteenth century; namely, the side opposing the theory of the occurrence of spontaneous generation under present conditions of life. Leeuwenhoek was acquainted with the experiments of Redi (1668), and these were convincing to him so far as the origin of maggots was concerned; he had also discovered with his microscopes the minute eggs of the water mussel and of insects, and had traced stages of their development. He was therefore convinced that life is not spontaneously generated; at the same time he was ready to entertain as a hypothesis the possible spontaneous origin of the microscopic animalculæ which he himself had discovered.

As compared to Malpighi, Swammerdam and Leeuwenhoek,

the other observers of the period were of secondary importance. The work of these three men was the dominant feature of seventeenth century natural history, it represented the progress in microscopical observation and in the knowledge of structure, development and physiology after Harvey.

COMPARISON OF THE THREE MEN

We see in these three gifted contemporaries different personal characteristics. Leeuwenhoek, the composed and strong, attaining an age of ninety-one; Malpighi, always feeble in health, but directing his energies with rare capacity, reaching the age of sixty-seven; while the great intensity of Swammerdam stopped his scientific career at thirty-six and burned out his life at the age of forty-three.

They were all original and accurate observers, but there is variation in the kind and quality of their intellectual product. The two university-trained men showed capacity for methodical and coherent observation; they were both better able to direct their efforts towards some definite end; Leeuwenhoek, with the advantages of vigorous health and long working period, lacked the systematic training of the schools, and all his life wrought in discursive fashion; he left no coherent piece of work of any extent such as Malpighi's *Anatome plantarum* or Swammerdam's *Anatomy and Metamorphosis of Insects*.

Swammerdam was the most critical observer of the three, if we may judge by his labors in the same field as Malpighi's on the silkworm. His descriptions are models of accuracy and completeness, and his anatomical work shows a higher grade of finish and completeness than Malpighi's. Malpighi, it seems to me, did more in the sum total than either of the others to advance the sciences of anatomy and physiology, and through them the interests of mankind. Leeuwenhoek had larger opportunity; he devoted himself to microscopic observations for many years, but he wandered over the whole field. While his observations lose all monographic character, nevertheless they were important in

opening new fields and in advancing the sciences of anatomy, physiology, botany and zoölogy.

The combined force of their labors marks an epoch characterized by the acceptance of the scientific method and the establishment of a new grade of intellectual life. Through their efforts and those of their contemporaries of lesser note the new intellectual movement was now well under way.

CHAPTER XIII

MONOGRAPHS ON INSECTS AND OTHER MINUTE ANIMALS

As we go on with the story of the growth of biology we see that its component parts, which in a simple stage were merged in a generalized whole, become developed into independent subjects of investigation; and still they retain a vital connection with the parent stock. It becomes our task to observe the concurrent growth of these parts one at a time without losing sight of their organic connection. The differentiation of biological subjects became well marked in the eighteenth century; in natural history, it was the century of Ray, Linnæus and Buffon, in physiology, of Spallanzani and Haller. For the time being we postpone consideration of the contributions of those men and give attention to the development of a branch of investigation closely allied to that of Malpighi, Swammerdam and Leeuwenhoek.

The observations of Malpighi and Swammerdam made the structure and life histories of insects favorite lines of study. There is something of an intriguing nature in the study of insect anatomy. Some of the greatest beauties of organic nature are displayed in the internal structure of insects. The delicate tracery of the organs, their minuteness and perfection, are well calculated to awaken surprise and to give rise to feelings of exaltation. Well might those early observers be moved to enthusiasm over their researches in insect anatomy; every excursion into this domain revealed beautiful pictures of a mechanism of exquisite delicacy. Swammerdam's observations and his beautifully executed pictures remained in manuscript for nearly seventy years after he had completed them. When finally published in 1737–1738 as the *Biblia naturæ* they gave an impulse to the study of insect anatomy and insect metamorphosis.

The first structural study, after Swammerdam's, to which we must give attention is that of Lyonet, who produced in the middle of the eighteenth century one of the most extraordinary monographs in the field of minute anatomy. This like Malpighi's *Study of the Silkworm* was the anatomical investigation of a single form, but it was carried out in much greater detail. The one hundred thirty-seven figures on the eighteen plates are models of close observation and fine execution of the sketches.

LYONET

Lyonet (also written Lyonnet) was a Hollander, born at The Hague, in 1707. He was a man of varied talents, a painter, a sculptor, an engraver, and a very gifted linguist. It is reported that he was skilled in at least eight languages, and at one time he was the cipher secretary and confidential translator for the United Provinces of the Netherlands. He was educated as a lawyer, but, from interest in the subject, devoted most of his time after he was thirty to engraving objects of natural history and to minute dissections. He died in 1789 aged eighty-one years. At the age of thirty-five we find Lyonet engaged in engraving pictures for Lesser's *Theology of Insects* (1742); and, at thirty-seven, for Trembley's famous treatise on the fresh water polyps (1744).

His Great Monograph. Finally Lyonet decided to branch out for himself, and produce a monograph on insect anatomy. After some preliminary work on the sheep-tick, he selected for special investigation the caterpillar of the goat-moth, which feeds upon the willow-tree. His work, first published in 1750, bore the title *Traité Anatomique de la Chenille qui ronge le bois de Saule*. In exploring the anatomy of this form, he displayed not only patience, but great skill as a dissector, while his superiority as a draughtsman was continually shown in his sketches. He engraved his own figures on copper. The drawings are very remarkable for the amount of detail that they show. He dissected his form with the same thoroughness with which medical men have dissected the human body. The superficial muscles were

carefully sketched and were then cut away in order to expose the next underlying layer which, in turn, was sketched and then removed. The amount of detail involved in this work may be in part realized from the circumstance that he distinguished 4,041 separate muscles. His sketches show these muscles accurately

FIG. 68. — PIERRE LYONET, 1707–1789. (From an old print done on copper.)

drawn, and the principal ones are lettered. When he came to expose the nerves he followed their minute branches to individual small muscles and sketched them, not in a diagrammatic way, but as accurate drawings from the natural object. The breathing-tubes were followed in the same careful manner, and

the other organs of the body were all dissected and drawn with remarkable thoroughness. Lyonet was not trained in anatomy as Swammerdam and Malpighi, but being a man of unusual patience and manual dexterity, he accomplished notable results. His great quarto volume is, however, merely a description of the figures, and lacks the insight of a trained anatomist. His skill as a dissector is far ahead of his knowledge of anatomy, and he becomes lost in the details of his subject.

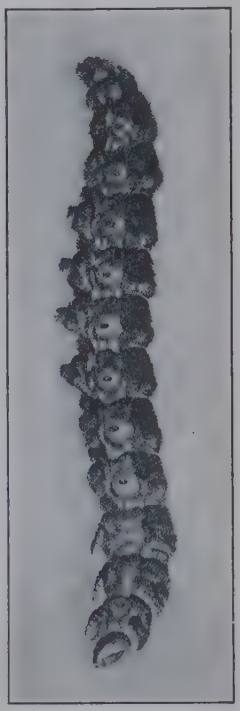

Fig. 69. — Larva of the Willow Moth. (Lyonet's monograph, 1750.)

Extraordinary Quality of the Drawings. A few figures will serve to illustrate the character of his work, but the reduced reproductions of the sketches cannot do justice to the copper plates of the original. Figure 69 is an enlarged view of the caterpillar upon which he worked — the full-grown form being about one inch in length. When the skin was removed from the outside the muscles came into view as shown in Fig. 70. This is a view from the ventral side of the animal. The sketch at the left shows, on one side the superficial layer of muscles, and on the opposite side, the next deeper layer. The sketch at the right shows one of his dissections of the central nervous system and the nerves; the muscles are indicated in outline, and the distribution of nerves to particular muscles is shown. In the original copper engravings these figures are four inches in length.

Lyonet's dissection of the head is an extraordinary feat of delicate manipulation. The entire head is not more than one-quarter of an inch in diameter, but in a series of seven dissections he shows all the internal organs of the head. Fig. 71 represents

two sketches exhibiting the nervous ganglia, the air-tubes, and the muscles of the head in their natural position.

Fig. 72 is a much enlarged view of the nervous system of the head, including the extremely small nervous masses that have been designated the " sympathetic nervous system."

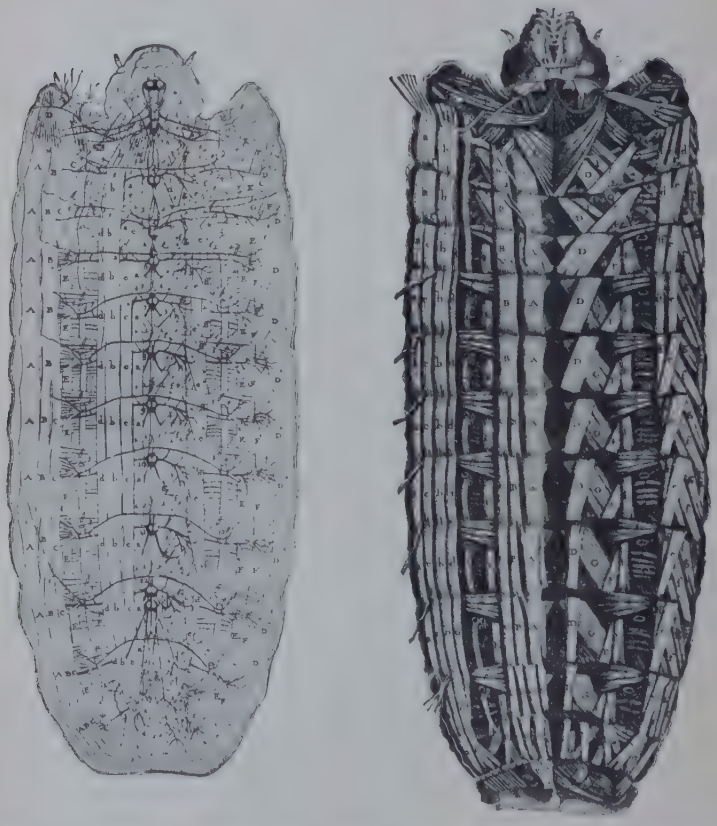

FIG. 70. — MUSCLES (RIGHT), AND CENTRAL NERVOUS SYSTEM WITH THE NERVES (LEFT) OF THE WILLOW MOTH. (From the same book.)

The remarkable character of the sketches in Lyonet's monograph created a sensation. The existence of such complicated

structures within the minute body of an insect was discredited, and, furthermore, some of his critics declared that even if such a fine organization existed, it would be beyond human possibilities to expose the details as shown in his sketches. Lyonet was accused of drawing on his imagination. In order to silence his critics, he published in the second edition of his book, in 1752, pictures of his instruments (Fig. 73) together with a description of his methods.

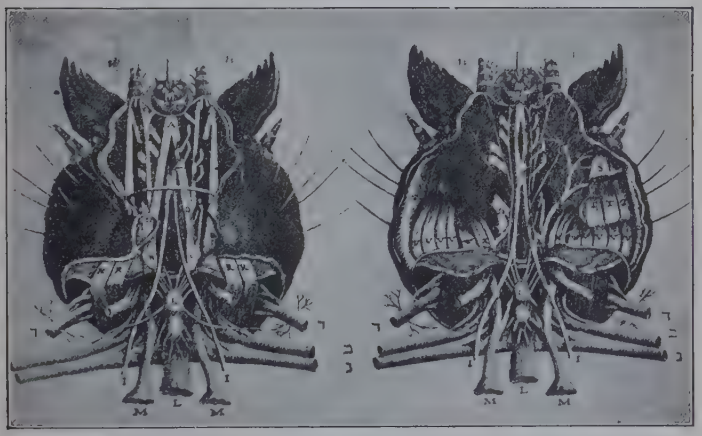

Fig. 71. — Dissection of the Head of the Same Animal.

Lyonet intended to work out the anatomy of the chrysalis and the adult form of the same animal. In pursuance of this plan, he made many dissections and drawings, but, at the age of sixty, on account of the condition of his eyes, he was obliged to stop all close work, and his project remained unfinished. The sketches which he had accumulated were published later, but in quality they fall short of those illustrating the *Traité Anatomique*.

Réaumur, Bonnet, Rœsel, and De Geer

Running parallel with these investigations of minute anatomy, there were observations and publications on the form, the

habits, and the metamorphosis of insects that were of wider scope than the researches of Lyonet and did more to extend the knowledge of insect life. Réaumur and Bonnet, in France, Rœsel, in Germany, and de Geer, in Sweden, were distinguished observers in this line. The treatises of Réaumur and de Geer were extensive, filling six and seven thick quarto volumes, and

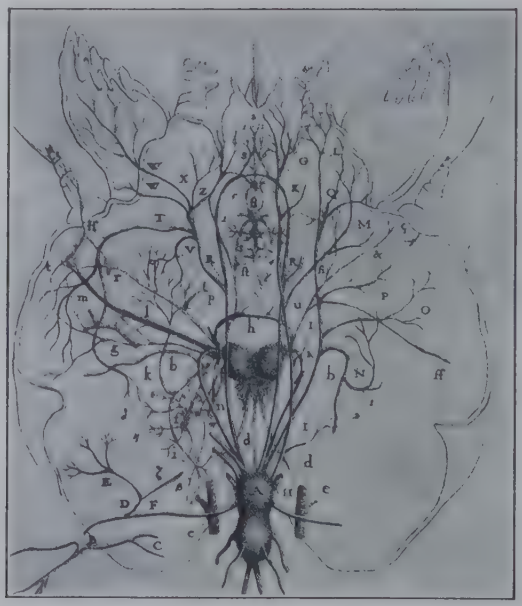

Fig. 72. — Brain and Nerves of the Head.

both series took the title so much used by the French of *Mémoires pour servir à l'Histoire des Insectes*.

Réaumur (1683–1757), Fig. 74, preceded Lyonet, having published his famous six-volume history of insects between 1734 and 1742. He was an accurate observer whose influence on the progress of science was far-reaching. He was educated as a physician, but being financially independent, devoted his time chiefly to scientific investigation. For the greater part of his

life he lived quietly either at his estate in Saintong or at his country house at Bercy near Paris. He was distinguished for kindly and amiable personal qualities and for sympathetic help to young naturalists. Réaumur did much general scientific work having a bearing on the practical arts. He in-

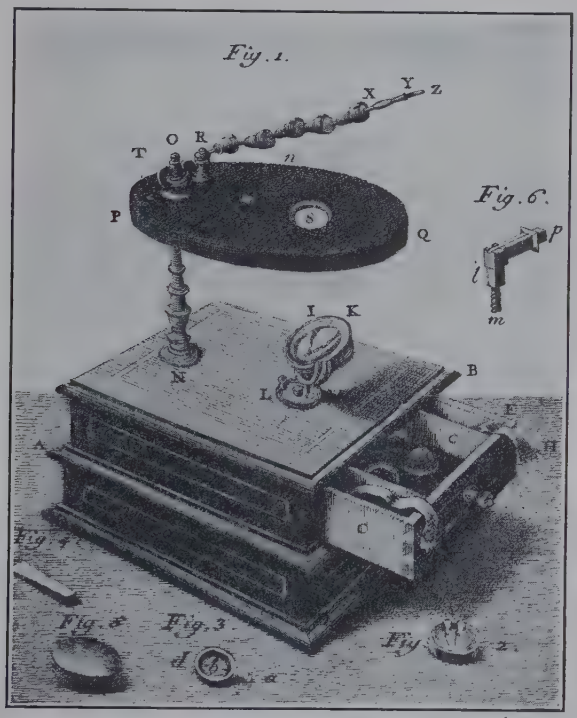

FIG. 73. — LYONET'S DISSECTING OUTFIT. (Edition of 1752, the Author's copy.)

vented the thermometer which bears his name. As a physiologist, he made ingenious experiments upon the digestive juices of birds and other animals, which later in the century were utilized and extended by Spallanzani.

"But of all the works of Réaumur, the most remarkable are

the *Mémoires pour servir à l'Histoire des Insectes,* of which six quarto volumes were issued between 1734 and 1742. His plan included a seventh volume which was left unfinished at death." These books so handsomely printed and illustrated by plates are still highly prized by entomologists. "The style is flowing

FIG. 74. — RENÉ-A.-F. DE RÉAUMUR, 1683–1757.
(Les Savants Modernes.)

and animated, and few books on natural history are so pleasant to read." Cuvier exclaims, "The *History of Insects* can be read with all the interest of the most absorbing romance." "Charm of style is however the least of his merits; he was one of the best observers that ever lived and enriched every topic with a profusion of new facts." (Miall.) It is a curious circumstance, that with all his powers of accurate analysis, he was careless as to the boundaries of his subject, and even included amphibians

and reptiles with the insects. There are many crudities and mistakes in the writings of the early naturalists which must not be allowed to deceive us as to their true merits. On the whole, they made substantial progress in helping advance human knowl-

FIG. 75. — CHARLES BONNET, 1720–1793. (Thornton, *New Illustrations of the Sexual System of Linnæus*, 1807.)

edge; their positive results of observation lived, while their vagaries fell by the wayside.

Charles Bonnet (Fig. 75), a young friend of Réaumur's, was greatly indebted to him for encouragement and for suggesting the topic of research upon which rests the fame of Bonnet as a naturalist. Réaumur had made observations on the generation of the Aphids, or plant-lice, which he passed on to Bonnet and

encouraged him to extend the observations. These Aphid-experiments were a sensation of the time. In fact, two subjects of great general interest emerged at this time — hydra-experiments of Trembley (see later) and the aphid-experiments of Bonnet. In the words of Miall: "About the year 1745 all well-read naturalists, and many people who were not naturalists at all, were strangely excited about the *pucerons* or aphids. It became known that a young man named Bonnet had just proved that aphids produced new generations without fertilization, and this singular exception to the ordinary course of nature created almost as great a stir as the seminal animalcules of Leeuwenhoek or the polyps of Trembley. The story of the aphids occupies the first volume of Bonnet's *Traité d'Insectologie*. Though spaced so widely as to occupy two hundred twenty-eight pages, it is no longer than many a review article, and may easily be read through in an evening. It is clear and interesting, devoid of technicalities, and suited in all ways to readers who are intelligent without being learned."

The propagation of aphids without fertilization — a process which has received the name of parthenogenesis — had been known to earlier naturalists, beginning with Leeuwenhoek, but Bonnet's experiments brought it to general attention. He showed the viviparous birth of aphids from unfertilized parents — carried through five generations — and, in fact, so long as suitable food is plentiful.

After these observations "a weakness of the eyes hindered him from attempting further work in natural history," and, like Weismann in the nineteenth century for similar reasons, Bonnet henceforth turned his thoughts to philosophy, and "wrote much that was once highly esteemed, though it has failed to endure." (See further under Embryology.)

The sketches of Rœsel von Rosenhof (Fig. 76) in his Insect Recreations (*Insecten-Belustigungen*, 1744–1761), a monthly publication that ran through four volumes — being continued four years after his death — are especially worthy of examination. Some of his exquisite illustrations in color are fine ex-

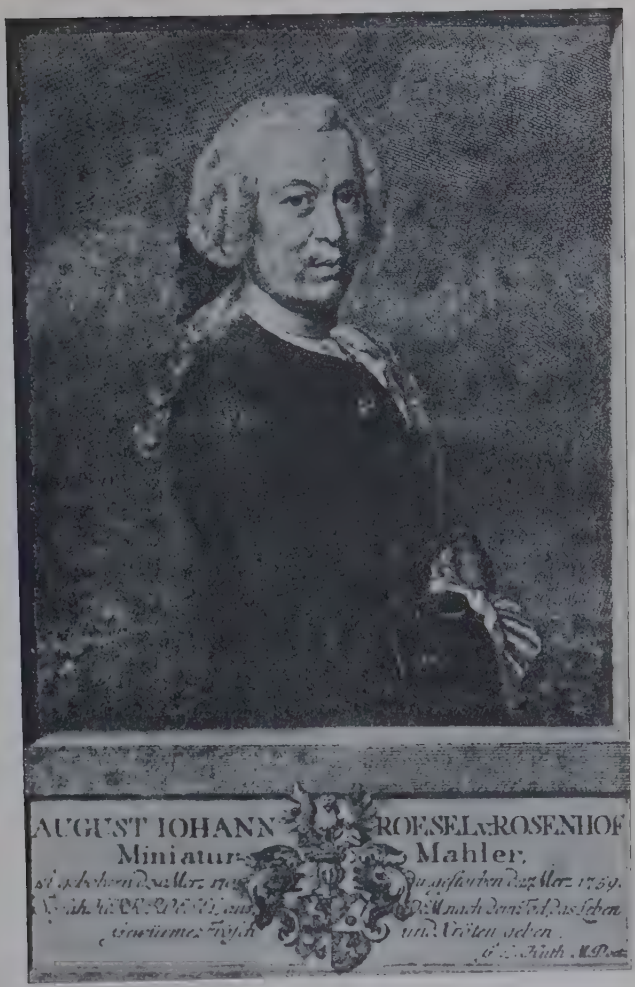

FIG. 76. — RŒSEL VON ROSENHOF, 1705–1759. (*Insecten Belustigungen.*)

amples of the art of painting in miniature. The name of Rœsel is also connected with the earliest observations (1775) of protoplasmic movement in the common amœba; he did not recognize it as living substance, and is not to be considered the scientific discoverer of protoplasm. Rœsel's comments on the crayfish, the anatomy of which he pictured, contains the amusing suggestion that the gill-bailer is an instrument with which the crayfish brushes its teeth. Rœsel also published a notable treatise on the Batrachians.

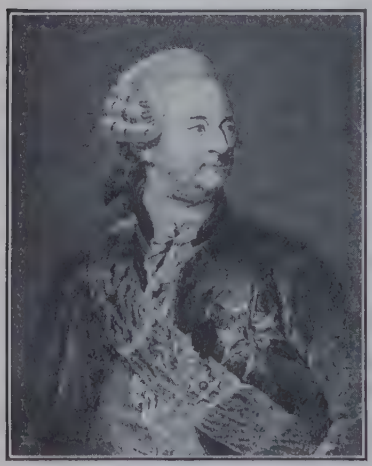

Fig. 77. — Charles de Geer, 1720–1778. (Frontispiece to *Mémoires pour servir à l'Histoire des Insectes*, 1742. From a painting by G. Lundberg.)

De Geer (1720–1778), taking Réaumur as his model, produced seven volumes of *Mémoires pour servir à l'Histoire des Insectes* published between 1752 and 1778. He came of a prominent and wealthy Dutch family long settled in Sweden. After taking his university degree in the Netherlands — the original country of his family — he returned to Sweden and attended the lectures of Linnæus at Upsala. The extensive illustrations of the book were engraved from his own drawings. "His classification of insects by wings and mouth-parts was better than any that had previously appeared, and resembles in many respects that which we still employ." (Miall.)

Straus-Dürckheim's monograph on insect anatomy

Insect anatomy continued to attract a number of investigators, but we must go forward into the nineteenth century before we find the subject taking a new direction and merging into its modern phase. The remarkable monograph of Straus-Dürckheim represents the next step in the development of insect anatomy

towards the position that it occupies today. His aim is clearly indicated in the opening sentence of his preface: "Having been for a long time occupied with the study of articulated animals, I propose to publish a general work upon the comparative anatomy of that branch of the animal kingdom." He was working under the influence of Cuvier, who, some years earlier, had founded the science of comparative anatomy, and whom Straus-Dürckheim recognized as his great exemplar. His work is dedicated to Cuvier, and is accompanied by a letter to that great anatomist expressing his thanks for encouragement and assistance.

Straus-Dürckheim (1790–1865) intended that "the general considerations" should be the chief feature of his monograph, but they failed in this particular, because, with the further developments of anatomy, including embryology and the cell-theory, his general discussions regarding the articulated animals became obsolete. The chief value of his work today lies in what he considered its secondary feature, *viz.*, that of the detailed anatomy of the cockchafer, one of the common beetles of Europe. Owing, therefore, to changed conditions, it takes rank with the work of Malpighi and Lyonet, as a monograph on a single form. Originally, he had intended to publish a series of monographs on the structure of insects typical of the different families, but that upon the cockchafer was the only one completed.

COMPARISON WITH THE SKETCHES OF LYONET

The quality of this work upon the cockchafer was excellent, and in 1824 it was accepted and crowned by the Royal Institute of France. The finely lithographed plates were prepared at the expense of the Institute, and the book was published in 1828 with the following cumbersome title: *Considérations Générales sur l'Anatomie comparée des Animaux Articulés, auxquelles on a joint l'Anatomie Descriptive du Melolontha Vulgaris (Hanneton) donnée comme example de l'Organisation des Coléoptères.* The one hundred nine sketches with which the plates are adorned

are very beautiful, but one who compares his drawings, figure by figure, with those of Lyonet cannot fail to see that those of the latter are more detailed and represent a more careful dissection. One illustration from Straus-Dürckheim will suffice to bring the achievements of the two men into comparison.

Figure 78 shows Straus-Dürckheim's sketch of the anatomy of the central nervous system. He undertakes to show only the main branches of the nerves going to the different segments of the body, while the corresponding figure of Lyonet brings to view the distribution of the minute terminals to particular muscles. Comparison of other figures — notably those of the dissection of the head — will bring out the same point, *viz.*, that Lyonet was more detailed than Straus-Dürckheim in his explorations of the anatomy of insects, and fully as accurate in drawing what he had seen.

Nevertheless, the work of Straus-Dürckheim is conceived in a different spirit, and is the first serious attempt to make insect anatomy broadly comparative.

COMMENT

Such researches as those of Swammerdam, Lyonet, and Straus-Dürckheim represent a phase in the progress of the study of nature. Perhaps their chief value lies in the fact that they embody the idea of critical observation. As examples of faithful, accurate observations these researches helped to bring about that painstaking study which is our only means of getting at basal facts. These men were all enlisted in the crusade against superficial observation. This had to have its beginning, and when we witness it in its early stages, before the researches had become illuminated by great ideas, the prodigious effort involved in the detailed researches may seem to be poorly expended labor. Nevertheless, though the writings of these pioneers have become almost obsolete, their work was of importance in helping to lift observations of nature to a point of greater accuracy.

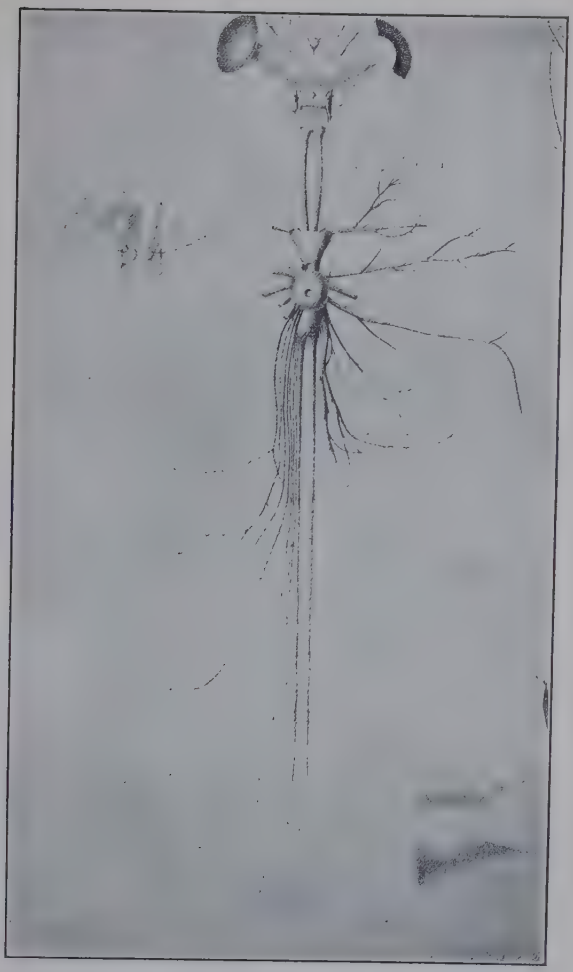

FIG. 78. — NERVOUS SYSTEM OF THE COCKCHAFER. (Straus-Dürckheim's Monograph, 1828.)

DUFOUR

Léon Dufour (1780–1865) "was an army surgeon who served with distinction in several campaigns and subsequently practiced as a doctor in the Landes." He showed great enthusiasm as a dissector of insects and "he attained great eminence as a naturalist." Henri Fabre, the exponent of popular writings on entomology in France, accords to Dufour the most gracious acknowledgements for the stimulus derived from his writings and for inciting him to his observations of the habits of insects. Dufour extended the work of Straus-Dürckheim by publishing, between 1831 and 1862, researches upon the anatomy and physiology of different families of insects. These researches are accompanied by fine pictures on lithographed plates. His aim was to found a general science of insect anatomy. That he fell short of accomplishing this end was owing largely to the absence of embryology and histology from his method of study.

NEWPORT

The thing most needed at this time was not greater devotion to details and a willingness to work, but a broadening of the horizon of ideas. This arrived in the Englishman, George Newport (1803–1854) who was remarkable not only for his skill as a dissector, but also for his recognition of the importance of embryology in elucidating the problems of anatomy. His article "Insecta" in Todd's *Cyclopædia of Anatomy and Physiology,* in 1839, and his papers in the *Philosophical Transactions* of The Royal Society between 1832 and 1844, which contain, in addition to insects, researches on myriapoda and crustacea, included this new kind of investigation. From 1851 to 1853, he also published, with illustrations, researches on impregnation of the ovum of amphibians. Von Baer, by his great work on the development of animals had founded embryology, in 1828, before the investigations of Dufour, but it was reserved for Newport to recognize its great importance as applied to insect anatomy. He saw clearly that, in order to comprehend his problems, the

anatomist must take into account the process of building the body, as well as the completed architecture of the adult. The introduction into his practice of this conception made his achievement a distinct advance beyond that of his predecessors.

LEYDIG

Just as Newport was publishing his results, the cell-theory was established, in 1838–1839, and this was destined to supply the basis for a new advance. The influence of the doctrine that

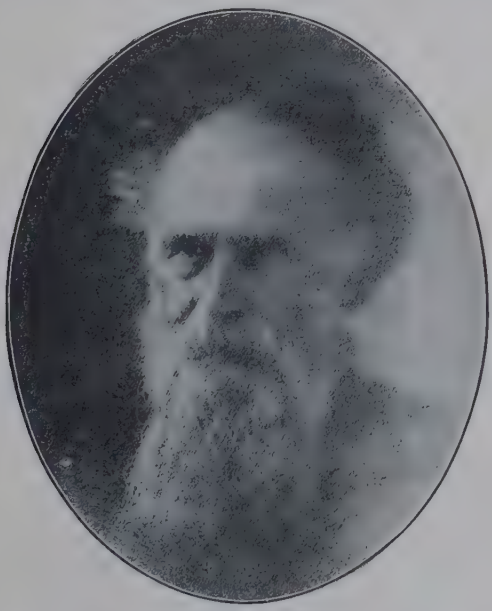

Fig. 79. — Franz Leydig, 1821–1908. (Picture loaned by Dr. William Wheeler.)

all tissues are composed of similar vital units, called cells, was far-reaching. Investigators began to apply the idea in all directions, and there resulted a new department of anatomy, called histology. The subject of insect histology was an unworked field, but manifestly one of importance. Franz Leydig (Fig. 79)

entered the new territory with enthusiasm, and, through his extensive investigations, all structural studies upon insects assumed a new aspect. In 1864, appeared his *Vom Bau des Thierchen Körpers,* and his plates on comparative anatomy, which, together with his special articles, created a new kind of insect anatomy based upon the microscopic study of tissues. The applications of this method are easy to see; just as it is impossible to understand the working of a machine without a knowledge of its construction, so a knowledge of the working units of an organ is necessary to comprehend its action. For illustration, it is perfectly evident that we cannot understand what is taking place in an organ for receiving sensory impressions without first understanding its mechanism, and the nature of the connections between it and the central part of the nervous system. The sensory organ is on the surface in order more readily to receive impressions from the outside world. Also, the sensory cells are modifications of surface cells, and, as a preliminary step to understanding their particular office, we must know the line along which they have become modified to fit them to receive stimulations.

Furthermore, if we attempt to follow the path by which the surface stimulations reach the central nervous system and affect it, we must investigate all the connections. It thus appears that we must know the intimate structure of an organ in order to understand its physiology. Leydig supplied this kind of information for many organs of insects. In his investigations of this nature, we see the beginnings of that delicate work upon the microscopic structure of insects which is still going forward.

SUMMARY

In this brief sketch we have seen that the study of insect anatomy, beginning with that of Malpighi and Swammerdam, was lifted to a plane of greater exactitude by Lyonet and Straus-Dürckheim. It was further broadened by Dufour, and began to take on its modern aspects, first through the labors of Newport, who introduced embryology as a feature of investigation,

and, finally, through Leydig's step in introducing histology. In the combination of these two observers, the subject for the first time reached its proper position.

The influence of the dissection of insects upon other studies of anatomy was very great by way of improving methods and sharpening attention upon fine details. Investigation of the anatomy of insects requires delicate manipulation and forces exact observation, and, as Cuvier maintained, it affords the best training for entering the field of comparative anatomy. Accordingly, it is to be presumed that the period of insect-dissection, already described, had much to do with improving anatomical studies. In the last part of the eighteenth and the first part of the nineteenth century the science of comparative anatomy was founded and took its place as a major subject of study.

MODERN STUDIES ON INSECTS

The very special development of entomology in the nineteenth century is too extensive to follow here. However, insects are so interrelated with general topics, and the later investigations of them have played such a part in the history of science, that some further comment will be in keeping. From whatever point of view these animals have been studied, they have awakened interest and enthusiasm among naturalists, and their investigation has had a direct bearing on public health and human welfare. The mosquito-problem, alone, has modified history, both in ancient and in recent times. It has even been conjectured that the decline of Roman civilization was in part due to the prevalence in the swampy campagna of mosquitoes, bearing disease-germs of malaria and other disorders. We know for a certainty that the control of mosquitoes was the important factor in the construction of the Panama canal as well as in freeing Havana and the Gulf-ports of yellow fever.

In their life-histories some insects, as butterflies, bees, etc., exhibit in the clearest fashion and in the widest range the phenomena of metamorphosis — a process of great interest also in other animals. Hatching from the egg, in a form different

from the adult, many insects pass through various stages of moults as larvæ, then enter the quiescent or pupa stage, and emerge from their cases as adults.

In reference to the fertilization of flowers, insects exhibit some of the most interesting relations of nature. With remarkable adroitness they extract the nectar of flowers, and at the same time carry pollen from flower to flower, and promote cross-fertilization.

But it is in reference to their habits that they show the most extraordinary display of instinctive intelligence and complex behavior. Those forms such as ants, bees and social wasps, living in social communities, that are well organized as to division of labor and concerted action, may be properly regarded as animals of dominant intelligence.

Fig. 80. — J. Henri Fabre, 1823–1913. (Legros, *Fabre, Poet of Science*, 1917.)

The French entomologist, J. H. Fabre (1823–1913), devoted a long life to observation of insects, showing especial aptitude for searching out their habits. He has related his observations in voluminous and charming writings, which reached the dimensions of ten volumes under the title of *Souvenirs Entomologiques*. These memoirs have been translated into English and have a wide circulation. Fabre (Fig. 80) on account of his talents as an observer, his gifts as a writer and his direct appeal to a non-technical audience, is probably more generally known than any other entomologist.

Other entomologists, more important from a scientific standpoint, but who have addressed chiefly a scientific audience, are less generally known. Their names even are too numerous to

list, but as examples, a few may be mentioned such as Brandt, Graber, Heymons, Weismann, Janet, Forel, Pol Marschal (in the same line as Fabre), Korschelt, Heider, and Wheeler in embryology of insects.

On account of their relation to the transmission of diseases, insects have become of world-wide interest, and some of them have acquired a most evil notoriety. This topic leads into experimental and preventive medicine which will be dealt with in the chapter on Pasteur and his school.

OBSERVATIONS ON OTHER MINUTE ANIMALS

The studies of minute structure in the seventeenth and eighteenth centuries were by no means confined to insects; investigations were carried forward on a number of other small forms of life. As we have seen, the aphid-experiments of Bonnet received wide notice, studies of the minute crustacea, commonly called "water-fleas," which are just large enough to be distinguished by the unaided eye, and especially, experiments on the small fresh water hydra, were subjects of commanding interest. The structure of snails and of tadpoles was investigated, and early studies on embryology were carried on by Haller, Wolff and other observers. The microscope was constantly used in investigation by many observers such as Joblot, Spallanzani and Müller. We should also remember that during this period the microscopic structure of plants, first revealed by Malpighi, Grew, and Leeuwenhoek, was a subject of investigation. The story of the discovery of Protozoa and Bacteria has been given in Chapter XI and here we take up the studies in the growth and regeneration of Hydra.

TREMBLEY

The biological topics which aroused the greatest interest, in the middle of the eighteenth century, were the aphid-experiments, already mentioned, and the growth and regeneration of hydra as revealed by the studies of Trembley and Baker.

Abraham Trembley, a relative of Charles Bonnet, was born

at Geneva, Switzerland, in 1700, and lived till 1784. He became tutor to the two sons of the Hon. William Bentick, an Englishman living in the suburbs of The Hague. This position took Trembley to Holland about 1740, and it was there that he achieved fame from his investigations of the small fresh-water animal now known as "Hydra." This is a tubular animal, about the size of a small knitting needle, varying in length from a half-inch to two inches, and having a mouth at one end surrounded by tentacles. It is now one of the common animals seen in biological laboratories. Trembley's observations were not confined to the structure, form, and general appearance of the animal; he experimented with it by cuttings and got results of unusual significance.

This small fresh-water polyp was known long before Trembley's observations of it. Leeuwenhoek, in 1703, had supplied the first printed sketch of the animal, and the Englishman, Henry Baker, had published a small book, in 1743, entitled *An Attempt Towards a Natural History of the Polype*. This was the year before the appearance of Trembley's celebrated treatise. Baker, however, had received his first specimens of the hydra from Trembley — through the President of the Royal Society — and he gave credit to Trembley, not only for providing specimens, but also for the discovery "of their amazing reproduction after being cut in pieces." Baker says that Trembley's work on hydra began in 1739, but this is probably a mistake, because Trembley did not go to The Hague where he collected his first hydra-material, until the year 1740, and, furthermore, Trembley says in the preface of his book, published in 1744, that his observations had extended over a period of three and one-half years. Inasmuch as these discoveries are related to the extensive development of studies on the regeneration of animals in the last part of the nineteenth century, they are of more than passing interest.

The original edition of Trembley's treatise is a handsome volume of three hundred twenty-four quarto pages, published at Leyden in 1744 under the title: *Mémoires pour servir à l'histoire*

d'un genre de Polypes d'eau douce, à bras en forme de cornes. The Paris edition of the same date is in two small volumes (six and one-half by four inches) and is inferior; it also lacks the

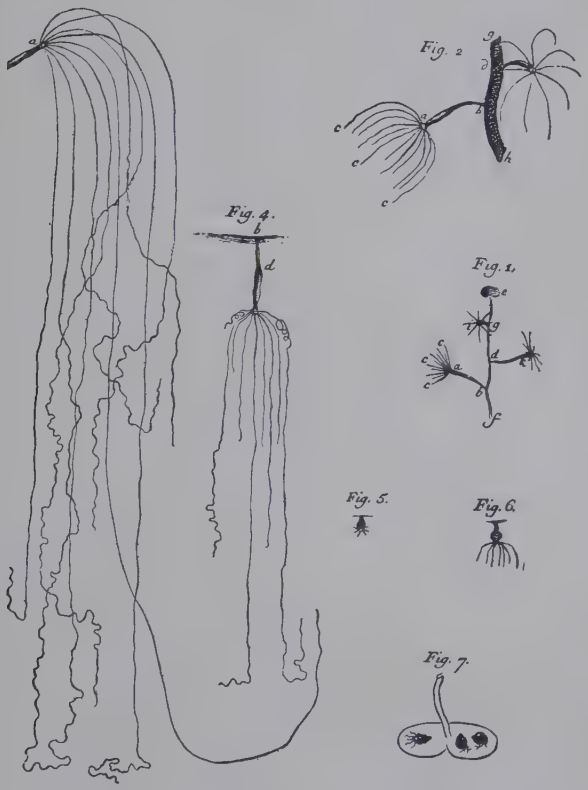

FIG. 81. — TREMBLEY'S ORIGINAL SKETCHES OF HYDRA, 1744.

vignettes of the Leyden edition. Both editions are illustrated by thirteen plates of figures — those on the last eight plates having been engraved by Lyonet.[1]

[1] The John Crerar Library of Chicago has a copy of the Paris edition which belonged to H. Milne-Edwards.

By delicate manipulation, Trembley turned polyps inside out, and prevented their return to the normal condition by thrusting bristles through their bodies. He cut them into four longi-

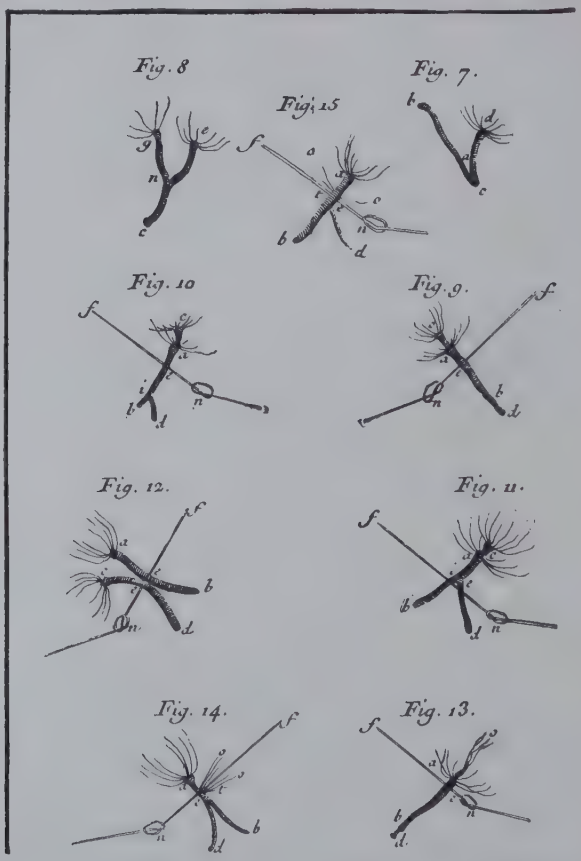

FIG. 82. — ILLUSTRATING SOME OF TREMBLEY'S EXPERIMENTS WITH HYDRA, 1744.

tudinal strips, each of which regenerated a complete animal; he joined fragments of different animals together and produced abnormal forms — seven-headed hydras, and others.

The question of its animal or plant nature perplexed him for a long time; the polyp multiplied by budding and by cuttings, like a plant, but it captured with its tentacles, and fed voraciously upon small crustacea and other minute animals inhabiting the water in which it lived. Finally, he concluded that it was of animal nature, as did Réaumur, to whom he submitted his specimens of study, although in this conclusion Réaumur had a conversion, for earlier he had pronounced corals and related zoöphytes to be plants and been opposed by Peysonnel and by de Jussieu. The squirming and groping tentacles of the animal led Réaumur to suggest for it the name of "polyp" — the English form of the Greek word for cuttle-fish. The extraordinary powers of regeneration exhibited by the animal, after being cut into pieces, — simulating the reconstruction and multiplication of the heads of the fabled hydra of classical stories — caught the fancy of Linnæus, who in his classification gave it the name of "hydra" which it still retains.

The question of the animal or vegetable nature of hydroids and corals — relatives of hydra — was much debated at that time. Often, in the old herbals, we find corals figured as plants, but, ultimately, the zoöphytes (plant-animals) were recognized as animals by all naturalists.

"The discoveries of Trembley and Bonnet were followed by a number of experiments on the multiplication of animals of low grade by artificial fission. Réaumur found that planarians and other worms could be increased in this way. The botanist, Bernard de Jussieu, experimented on star-fishes, and made it clear that they could at least reproduce lost rays" (Miall). Thus, largely through the experiments of Trembley, was opened a subject of the highest scientific interest but which for a long time remained undeveloped — the regeneration of lost parts. It has generally been overlooked that Baker's book was a pioneer publication on the subject. It was overshadowed by the superior treatise of Trembley and was practically lost sight of — Woodruff, in 1818, found only one mention of it in the literature

lists on regeneration. The recent studies of experimental morphology and regeneration of animals have taken up the subject where it was left by the pioneer investigators of the eighteenth century, and their results have been of great service in the study of certain physiological aspects of animals.

CHAPTER XIV

GESNER AND OTHER PIONEER NATURALISTS

In this chapter we turn from structural and experimental studies with organized beings to consider the development of natural history from the sixteenth to the eighteenth century.

A new type of naturalists arose after the Renaissance; observations of nature became more exact and more specialized and treatises on natural history began to be illustrated by sketches made direct from nature. Different men gave especial attention to different phases of natural science; while Vesalius was making anatomy exact, while Harvey was introducing experimental methods, and while microscopical studies were beginning, there was a parallel development of knowledge of plants and animals in general which led on to their systematic classification. Gesner, who was the most important pioneer naturalist dealing in a broad way with animals and plants, was a contemporary of Vesalius, and it was nearly two centuries after his time that the systematic classification was formulated and culminated in Linnæus. Of course, the classification of animals and plants came about gradually through the labors of a number of naturalists and we lead up to Linnæus by treating briefly of his forerunners.

The huge encyclopædias, or knowledge-books of the thirteenth century, which were considered in Chapter VI, became the chief source of information about animals and plants from the time of their production up to the middle of the sixteenth century. Those parts of the knowledge-books which dealt with animals, plants and stones were compilations from Aristotle and other writers down to the thirteenth century — with scarcely any personal observations. The next advance came through a reworking of the material left by Aristotle and other writers with the addition of personal observations of the writer. The writings

of the ancients were still needed as a prop because natural history was not sufficiently developed for the creation of an entirely new and original work based on the author's own observations. Even in the sixteenth century the frank return to Aristotle was an advance and the application of his method to observations of nature was the hope of further progress.

WOTTON

Comments on Aristotle's *Historia animalium* were made, and in course of time independent treatises upon animals began to appear — still based upon Aristotle as a model, and using his material. One of the first to modify Aristotle to any purpose was the English physician, Edward Wotton, who, in 1552, published a volume on the distinguishing characteristics of animals (*De differentiis animalium*). The preface and colophon are dated 1551, but the title-page shows the date 1552. This was a complete treatise on the zoölogy of the period, including some comments on the races of mankind. The work was based upon Aristotle but the author introduced some new matter, and also added the group of Zoöphytes, or plant-like animals of the sea. Wotton also left a sketch of the history of insects afterwards used by Mouffet. Although embracing ten books, it was by no means so ponderous as the treatises of Gesner, Aldrovandi, and Jonston which followed it, and, being without illustrations, as well as somewhat formal and dry in composition, it never acquired the great popularity of the three works just mentioned. What the people wanted to help in the identification of animals was pictures along with descriptions.

The author, Edward Wotton (1492–1555), was born at Oxford, studied at Magdalen College, and afterward traveled several years in Italy. He took his medical degree at Padua, and later held high office in the College of Physicians, and has been described as "the first English Physician who made a systematic study of natural history." He was a studious and exact man and this work was the product of his best effort. Unlike the famous *Historia animalium* of Gesner and other similar

books of the nearby period, Wotton's book was not reproduced even in a second edition, nor was it translated out of the Latin into any other language. Its circulation, therefore, was not extensive, and being read only by a limited number of the learned, it did not exert a great influence on the progress of zoölogy. The book, which is now rare, is a fine example of type and printing in the time of Edward VI to whom it is dedicated. It was printed in Paris, and is regarded by collectors as "unsurpassed in typographical excellence by any contemporary work." [1]

TURNER AND OTHERS

Englishmen took no leading part in the advancement of natural history in the sixteenth century; the foremost naturalists were then on the Continent. Nevertheless, the brilliant part played by Harvey in physiology in the seventeenth century, and in physical sciences, by Newton and his colleagues of the Royal Society, served a little later to establish the high position of England in science. One of the English naturalists who should not go unmentioned was William Turner, student of natural history, physician, and preacher. In 1544, the year after Vesalius published his path-breaking book on the human body, William Turner published his best book — that on the Birds mentioned by Aristotle and Pliny. The work is valuable, however, not on account of his treatment of the birds known to Aristotle and Pliny, but for his additions on the birds of England. In this he showed discernment and such good powers of description, that in 1903 this book was translated from Latin into English by Mr. Evans. Turner had studied botany in Italy under the eminent Luke Ghini and he was personally acquainted with Gesner. His *New Herball,* published in English, in 1555 and later, is of secondary importance.

In the interval between Vesalius and Harvey, in addition to the extensive treatise of Gesner, there appeared several illus-

[1] I have had for examination the fine copy in its old original binding at the Library of Congress at Washington. Apparently, this is the only copy of Wotton's book in the United States.

trated treatises on particular groups of animals — those of Belon on Birds and of Rondelet on Fishes were the most notable. There were other writers on natural history of minor importance whose work must be passed over without comment.

BELON

Pierre Belon (1518–1564) wrote on his travels, on the Dolphin, on aquatic animals and on birds. His *History of the Nature of Birds* with descriptions and "naifs portraicts" drawn from nature is a famous treatise, printed in Paris, in 1555, the same year that Gesner's volume on Birds appeared.[2] Carus speaks of Belon's book as "a capital work in the history of the zoölogy of birds," but we must remember that it was a work of the sixteenth century and is judged by the standards of the time. The author had studied under Valerius Cordus, at Wittenberg in 1540, and doubtless owed much to that clear-minded and masterly describer. Nevertheless, Belon's descriptions are often slight and unmethodical. His pictures are of the most importance. They vary in quality but bear evidence of having been drawn from nature, and the best ones are quite truthful representations. In his introduction occurs the much cited comparison of the human skeleton (Fig. 84) and that of a bird (Fig. 85). The two skeletons are placed in the same position and the corresponding bones are identified. He took the true

FIG. 83. — PIERRE BELON, 1518–1564. (Nearly the same picture in his *Book of Birds*, 1555, marked "aged 36," but damaged by tearing. J. Crerar Library.)

[2] The copy I have used, "*L'histoire de la nature des Oyseaux, avec leurs descriptions et naifs portraicts retriez du naturel*," Paris, 1555, has one hundred fifty-eight woodcuts and three hundred eighty-one pages of folio text.

clavicle of birds (the wish-bone) for a special bone of birds and erroneously identified the human clavicle with the coracoids.

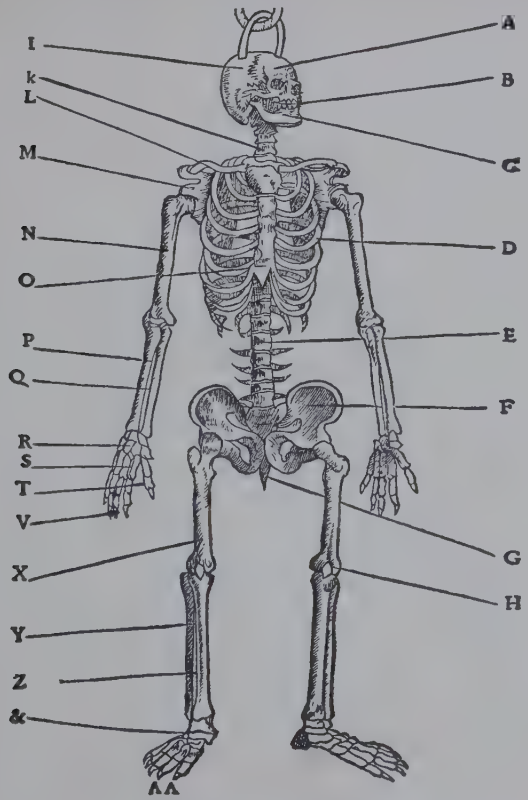

FIG. 84. — HUMAN SKELETON. (From Belon's *Book of Birds*, 1555.)

In his short chapter on the structure of birds he says that he had examined anatomically two hundred species.

RONDELET

Guillaume Rondelet (1507–1566) was professor of medicine and at one time Chancellor of the University of Montpellier.

He devoted much time to natural history and attracted a number of eminent students among whom were Clusius, J. Bauhin and de l'Obel. His two volumes on aquatic animals were published in

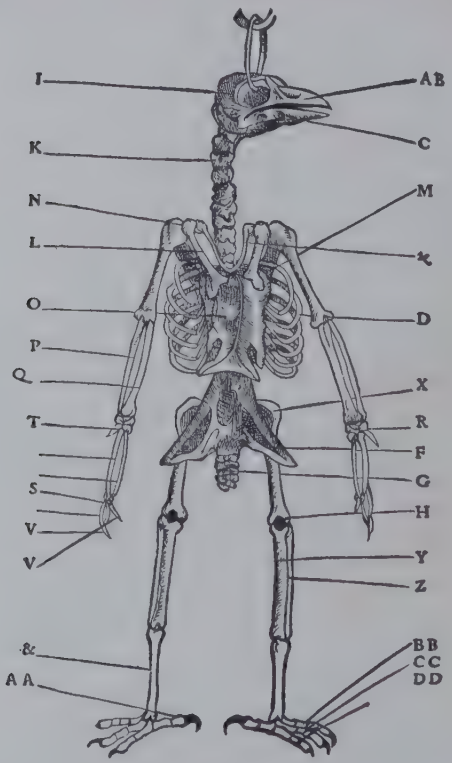

Fig. 85. — Bird Skeleton to Compare with Fig. 84.
(John Crerar Library.)

1554 and 1555, describing some two hundred fifty species and giving pictures of most of them. His work was more exact than that of Belon — who also wrote on fishes and other aquatic animals. Rondelet's works were much used by Willughby and Ray, and through these writers his results were transmitted to the later students of fishes.

GESNER

We come now to Gesner, whose extensive work on the History of Animals formed the starting-point of a greatly improved descriptive zoölogy. He supported his descriptions by extensive observations of animals. A treatment of this kind was a necessary step for progress. The author was a man of phenomenal industry and learning — the most learned naturalist of the sixteenth century. His wide interests and his varied attainments

FIG. 86. — GUILLAUME RONDELET, 1507–1566. (Jardine, *The Naturalist's Library*.)

FIG. 87. — CONRAD GESNER, 1516–1565. (From an old print.)

were exhibited in his writings and occupations. He was an accomplished linguist; he is recognized by librarians as a pioneer bibliographer,[3] a man harassed by circumstance and driven by a restless and eager acquisitiveness, sadly overworked and overwrought; a busy practitioner, working at night on literary and scientific projects. With all his personal projects pressing upon

[3] See Christian Bay, *Conrad Gesner, The Father of Bibliography, An Appreciation*. Bibliographical Society of American, 1916.

him he was generous of help and encouragement to others, arranging for the publication of neglected manuscripts (as that of Valerius Cordus, etc.), and giving of his time to writing prefaces and editing the works of others.

A brief account of his life has already been given in Chapter VIII together with a consideration of his service to botany.

It is his *Historia animalium* that brings him prominently into the history of science. This work began to appear in 1551, when Gesner was thirty-five years of age, and four of the five volumes were published by 1558. The fifth volume was not published until 1587, twenty-two years after his death. In preparing this work of colossal proportions, he had the assistance of numerous and widely-distributed correspondents who sent him local lore, specimens and observations. The information from these sources was amalgamated with his own observations and reflections. He had also sifted the writings of about two hundred fifty writers including the most ancient and the recent; thus his book is a recapitulation of all the knowledge of the sixteenth century regarding animals.

In Gesner's work we see a distinct progress upon the cyclopædia of the thirteenth century. The treatises of Albert,[4] Thomas of Cantimpré, and Bartholomew of England belong to the age of compilation and contain little of their own observation. In the interval between them and Gesner the method of verification had grown up, and recognition of the possibility of verification established it as a habit, and thus there was brought into existence a new type of scientific treatise. Gesner's method of verifying his facts marks the beginning of a new natural history, and still his treatise partakes of the character of the old cyclopædias, its enormous extent and endless comment make it as encyclopædic as the writings of the thirteenth century group. Besides copious illustrations, that which separates him from the others is his method of verification and the much greater extent of his personal observations. His descriptions are verbose, but discriminating in separating facts and observations from the

[4] Albert's is far superior to the other two.

fables and speculations which were included, for he did not entirely escape from old traditions. In a great general work of this nature the public expected as a matter of course to find some account of fabulous creatures, and it seems that Gesner did not wish to disappoint his readers. There are retained in his book pictures of the sea-serpent, the mermaids, and other fanciful and grotesque sketches, but Gesner is aware of the spurious nature of the stories and fables. None of the monstrosities originated with him and in his text he states doubts as to their authenticity and cites the authorities from which they are taken.

In order to contrast Gesner's method of treating the animal kingdom with the clear and concise method of Linnæus, which was established nearly two centuries later, it will be necessary to indicate the plan he adopted in his natural history. In his preface he outlines a uniform scheme of treating each animal under eight sections. Section 2 is the most important for zoölogy; in the other sections he shows much erudition and quaint information. Each section is intended to form a chapter, but in some cases one or more of the divisions are omitted. In a complete treatment he gives: (*a*) The names of animals in different languages; (*b*) the native country, habitat, general appearance, and the description of external and internal features; (*c*) treats of intellectual faculties, the environment, different kinds of movement, and diseases of animals; (*d*) the mental life, passions, habits and instincts; (*e*) utility of animals — hunting, rearing, domestic uses; (*f*) animals as food; (*g*) medical uses; (*h*) the literary history of animals, fables, uses in divination, sacred and emblematical animals, proverbs, etc. He makes no groups corresponding to Orders and Families. He says that there is so much doubt and uncertainty about the relationships of animals, that for convenience of reference he adopts an alphabetical arrangement within the larger groups which he treats in separate books. The alphabetical arrangement is not strictly followed, as he sometimes unites under one letter several obviously related forms with different names. While his plan resembles the mediæval rather than the modern, we should keep in mind

that he made many observations of his own and is somewhat critical with his references.

Brooks says: "One of Gesner's greatest services to natural science is the introduction of good illustrations, which he gives his reader by the hundreds." He borrowed illustrations extensively from contemporary sources: from Belon's "Birds"; from Rondelet's "Fishes"; from Breidenbach's travels; the picture of the rhinoceros came from Albrecht Dürer's drawing, and since it is by no means the best of the figures, we assume that Gesner

FIG. 88. — RABBITS FROM THE FIRST EDITION OF GESNER'S *Historia animalium*, ZURICH, 1551. (Northwestern University Library.)

was critical with his engravers and draughtsmen. Brooks says that his critical supervision of artists and engravers had its influence on the art of woodcutting. His descriptions, although verbose, are often well done, and combined with the illustrations "made science attractive without sacrificing its dignity," and his book became a great educational influence.

Gesner's pictures are so numerous and represent so many different animals that we cannot reproduce here a sufficient number to convey an idea of their quality. Three pictures, much reduced in size: the rabbit (Fig. 88), the mule (Fig. 89), and the

deer (Fig. 90), must suffice for his representation of mammals, and one, the basket star (Fig. 91), for the invertebrates. Many of his pictures of birds, fishes, and crustacea are very good.

FIG. 89. — WOODCUT OF THE MULE. REDUCED. (From the same book.)

The bulk of the completed work is often overstated as embracing "4500 folio pages." The original edition published at Zurich contains 3679 pages, and the Frankfort edition, according to my count, has 3299 pages with 1085 illustrations.

Gesner himself supervised the publication of only four volumes of the first edition; citations, however, are usually made from the Frankfort and other later editions, all of which are considerably altered and abridged. They also contain pictures and descriptions for which he was not responsible.[5] The various

[5] There is a fine copy of the rare first edition in the library of Northwestern University. Vol. I, on land quadrupeds, is more extensive as to text but contains

editions of Gesner were so much modified by other hands that they were not his own product. They were his as to general design, and contained extensive selections from his writings and the pictures which he had assembled; but with alterations,

Fig. 90. — Deer: From the Same Book.

sometimes additions, sometimes omissions, they still bear his name. They continued his name and had an influence on zoölogy

fewer pictures than the corresponding volume of the Frankfort edition. The latter also contains several additions of spurious animals.

for a long time. Many bibliographical details showing alterations might be cited but they have no place here. Since, however, some of them bear on the quality of Gesner's own work,

Fig. 91. — Basket Star: from the Same Book.

it should be said that the various editions from which naturalists commonly take this idea of Gesner as a describer contain much work of others less critical and exact than he was.

In fact, Gesner has suffered at the hands of editors and publishers. We can command space only for one example. Fig. 92 partakes of the fabulous, but as a historical relic showing a concession to popular taste, it is worth preserving. It so impressed the publisher of the Frankfort edition, printed thirty-eight years after Gesner's death, that he had it printed on the title page to intrigue the curiosity of a possible purchaser. So far as I can determine it did not appear in any edition during Gesner's lifetime and is to be looked on as one example of publisher's enterprise.

The description of this curious creature is a free translation

of the Latin in the Frankfort edition with small additions from Topsell's History of Four-footed Beasts, which purports to be a translation of Gesner's quadrupeds:

"*Of a wild beast in the new-world called Su.* There is a region in the new-found world called *Gigantes,* and the people thereof Patagones. Now because their countrey is cold, being far in the south, they clothe themselves with the skin of a beast

FIG. 92. — SKETCH OF THE "*Su.*" (From the Frankfort edition of Gesner, 1585–1604. John Crerar Library.)

called in their own language *Su,* for the reason that this beast liveth for the most part neer the water, therefore they call it by the name of *Su* which signifieth water. The true image thereof as it was taken by Thevetus, I have inserted, for it is of a very deformed shape, and monstrous presence, a great ravener and untamable wild beast. When the hunters that desire her skin set upon her, she flyeth very swift, carrying her young ones upon her back, and covering them with her broad tail; now for so much as no dog or man dareth to approach neer unto her (because such is the wrath thereof that she killeth all

that cometh neer her): the hunters dig several pits or great holes in the earth, which they cover with boughs, sticks and earth, so weakly that if the beast chance at any time to come upon it, she and her young ones fall down into the pit and are taken.

"This cruel, untamable, impatient, violent, ravening and bloudy beast, perceiving that her natural strength cannot deliver her from the wit and policy of men her hunters (for being inclosed she can never get out again), the Hunters being at hand to watch her downfall, and work her overthrow, first of all to save her young ones from taking and taming, she destroyeth them all with her own teeth; for there was never any of them taken alive; and when she seeth the Hunters come about her, she wareth, cryeth, howeleth, brayeth, and utereth such a fearful noysome, and terrible clamor, that the men who watch to kill her, are not thereby a little amazed, but at last being animated, because there can be no resistance, they approach and with their darts and spears wound her to death, and then take off her skin and leave the carcas in the earth. And this is all I find recorded of this most savage beast."

Considered from the standpoint of descriptions and illustrations, Gesner's *Historia animalium* remained for a long time the best work on zoölogy; all the learned men of Europe who were interested in nature turned to Gesner for their facts about animals, and since the numerous pictures also attracted the masses it became very popular and widely used. It was regarded as the standard reference on animals down to the time of Linnæus and it was, indeed, used for a long time afterwards, for there were no illustrations in Linnæus' *Systema naturæ*. The *Historia animalium* was republished in Latin, it was translated into German and many selections from the first volume into English.[6] This

[6] Topsell, Edward. *The Historie of Foure-footed Beastes*. Collected out of all the volumes of Conrad Gesner, and all other writers of the present day, London, 1607. Also, *The History of Four-footed Beasts and Serpents*. . . . Collected out of the writings of Conradus Gesner and other authors by Edward Topsell — whereunto is now added *The Theater of Insects* . . . by T. Moffett, etc., London, 1658. Vol. 1 is largely an abridged translation of books 1–5 of Gesner's *Historia animalium* with additions by Topsell.

great treatise on animals is still interesting on account of its pictures and its historical position, but the writing is now obsolete and it is not important to go into further details about it.

Gesner's History of Animals forms a link between the thirteenth century and Linnæus; he was the most influential zoölogist between Aristotle and John Ray, the immediate predecessor of Linnæus. His treatment of the animal kingdom was far in advance of Pliny's, but to avoid a possible misunderstanding it should be stated that between Aristotle and Ray there were two men of superior rank and greater influence. These were Galen and Vesalius who exerted such a profound general influence on the progress of natural history, but they were not zoölogists.

ALDROVANDI AND JONSTON

Two voluminous treatises on natural history — those of Aldrovandi, the Italian, and Jonston, the Scot — prolonged the period of "encyclopædists" for about a hundred years beyond Gesner. Aldrovandi's first volume was published forty-eight years after the first volume of Gesner's great treatise on animals and Jonston's first volume fifty years after Aldrovandi's, thus dividing the century after the beginning of Gesner's publication into two nearly equal parts.

Ulisse Aldrovandi (Fig. 93) was born at Bologna in 1522 (or 1527, the date being uncertain); at all events he lived to a ripe age, passing away at Bologna in 1605. He came of a patrician family and had worldly means at his command. Although he traveled and pursued studies at other places, he took his medical degree at the University of Bologna in 1553, practiced medicine there and taught philosophy and natural history for many years. According to his own account he studied law for seven years before devoting himself definitely to the pursuit of natural history. In the early years of these studies he planned a comprehensive work on animals and plants and for many years he assembled materials and pictures for this purpose. In the preface to the first volume of his *Opera* he says: "I retained the services of

one celebrated painter for more than thirty years at an annual salary of not less than two hundred golden pieces." He laid out a large sum of money in travels as well as in amassing collections of natural history specimens; finally he exhausted his own fortune and was voted grants of public funds by the enlightened Senate of Bologna.

Aldrovandi enjoyed the acquaintance of the leading naturalists of the day: Gesner, Rondelet, who encouraged him to study natural history, Matthioli and Fallopius. Originally he was deeply interested in botany and had studied that subject at Padua under the famous Luke Ghini. He showed public spirit and pride in his native city; he persuaded the Senate in 1567 to establish a botanical garden and was appointed its first director. Later he gave his natural history collections to the Senate and these formed the nucleus of the natural history exhibits in the public museum. Some of Aldrovandi's specimens still exist. His manuscripts went to the public library of Bologna, and paintings of animals made by artists at his expense, are still there.

FIG. 93. — ULISSE ALDROVANDI, 1522–1605. (Jardine, *The Naturalist's Library*.)

His books on animals were published in his old age, the first volume appearing in 1599, and he lived only to see five of the thirteen ponderous volumes [7] in print. He had already prepared volume six for the press and this was published by his widow. His remaining manuscripts were revised and completed by naturalists selected by the Senate, and the cost of their work

[7] I have used the 1646–1648 Edition of his *Opera* found in the Surgeon General's Library at Washington.

and the expenses of publishing the volume were defrayed from the public treasury. The wood engravings in Aldrovandi's treatise are coarser than those in Gesner's natural history of animals. In the Institute at Bologna are preserved twenty huge volumes of pictures of animals done in color. These are the originals from which the wood engravings were made. The originals were carried to Paris in the days of the Revolution (and subsequently, returned to Bologna); they were there in the time of Cuvier who speaks of them as being much superior to the reproductions.

Aldrovandi had the use of Gesner's works, a much longer working time, fewer distractions, and private means; with all these advantages we might expect that his production would be an improvement on Gesner's. But he was less critical and scholarly. He chose first to treat of Birds and that part of his work received his especial attention. He introduces more anatomy than Gesner and shows early stages of development of birds, about as Aristotle had done, observing in the embryo chick the beating of the heart on the third day of development and the arrangement of the blood vessels. He described animals from India, Africa and America that were not known in Gesner's time, but on the whole the quality of his work is not equal to that of Gesner.

John Jonston (1603–1675) was descended from an old Scotch family then living at Sampter in Poland. For a part of his university work he went to St. Andrews in Scotland. He became deeply interested in science and studied natural history and medicine at Frankfort, Leipzig, Wittenberg, Magdeburg, Berlin and Hamburg. He set out in 1631 in company with two young noblemen to visit England, France, the Netherlands and Italy. During these travels he remained long enough at Leyden to complete his studies for a medical degree which he received in 1632. Thereafter he settled to the practice of medicine in Silesia. His earlier writings seem to have been prompted by an enthusiasm for the wonders of creation. He wrote a book on the *Marvels of Nature*,[8] which was published in 1632, and in which

[8] *Thaumatographia naturalis in decem classes divisa.*

he gave an account of his travels and the various marvels which he knew. He wrote also on medicine, but soon began to devote most of his time to the large project of preparing a comprehensive work on the natural history of animals. This appeared successively in parts between 1650 and 1665. After completion the various parts were combined into a single work which in the later editions, after his death, bore the title *A Universal Theatre of all Animals* (*Theatrum universalis omnium animalium*). Though this book attained a considerable popularity and was a celebrated treatise up to the time of Linnæus, it was scarcely more than a repetition of the cuts of Gesner, Aldrovandi, Rondelet, Marcgrave, and other naturalists, with an occasional original drawing. It includes no personal observations and one can assign to it no high rank. The descriptions are very brief and inadequate and, of course, the lack of a scientific nomenclature is very apparent. The pictures, however, were carefully executed, and having been engraved on copper they had an attraction out of all proportion with the merits of the book. Jonston's work ends the series of the encyclopædists. It was followed by a number of abbreviated treatises made out of the more voluminous, but these did not have sufficient influence on progress to require specific notice.

The writings of Gesner, Aldrovandi, and Jonston assembled under one view the entire animal kingdom; they treated comprehensively of animals of the earth, air, and water, and the numerous illustrations gave them a semi-popular character. They served as sources to which the public as well as naturalists could turn for information about both local and exotic animals. In the transition between Aristotelian zoölogy of Wotton and the methodical classification of Linnæus they exerted a considerable influence on the progress of natural history. They assembled materials for future work and by their very extent they made felt the need of systematic classification of the great mass of individual facts. Thus they prepared the way for the scientific nomenclature and the classification of Linnæus.

Besides the lack of classification there is another fault com-

mon to all these books — they treated of the external form and general appearance of animals without making use of structure and development as a feature of determining rank and relationship. This defect was corrected by the development of the science of comparative anatomy after Linnæus had led the way to a systematic classification of animals and plants. The growth of comparative anatomy was followed by the closely allied branch of embryology, and under the influence of these two sister-sciences natural history entered its modern phase.

A view of the natural history of the era of Gesner would be incomplete without some mention of other books of the period which were written from a different viewpoint. The interests of the people as a whole were varied, and, since the books of Gesner and his confrères were not addressed directly to the religious instincts of mankind, it was natural that a certain class of readers should wish for books bringing into prominence the wisdom of God shown in his creations. Soon after the publication of Gesner's *Historia animalium,* and before Aldrovandi's works had appeared, the German pastor, Frey, published (1595) a book for pious Christian readers on *Animals of the Bible.* There were other books of similar character published soon after, but that of Frey may be taken as representing the tendency. These books were in a general way a more modern and extended form of the old sacred natural history of the *Physiologus* to which reference has been made in previous pages.

Another class of books dealing more or less with natural history arose in connection with voyages to distant lands. In fact, many of the books of travel and exploration of the sixteenth and seventeenth centuries contain incidental contributions to natural history. As early as 1482, Breidenbach, in his book of travels, published a plate of animal-pictures, giving among others the first printed illustration of the giraffe sketched from nature; Columbus brought back skins of animals, and Queen Isabella commissioned him especially to collect birds; Clusius made pictures and descriptions of animals and plants of the "West Indies"; the Spanish physician, Hernandez, collected

natural history specimens, between 1593 and 1600, in Mexico (he says that he made pictures of animals and plants to the number of 1200); Oviedo (1526) made known certain plants and animals of South America; Magellan's associates brought back observations on plants and animals; and in various publications some of the animals and plants of Africa and the Far East were made known by missionaries and medical men.[9]

In addition to contributions of this nature, which were chiefly narratives, there were treatises devoted specifically to natural history written by men attached to semi-scientific expeditions, or who went as individual scientists to foreign parts and lived for several years on the terrain which was under observation. Of the latter kind, the publications of Piso and Marcgrave on the natural history of (north-eastern) Brazil are the most remarkable. These men were connected with a semi-military enterprise set on foot by the Dutch West India Company. The expedition was under the leadership of Count Johann Moritz, who was soldier, statesman and lover of science. He took with him (1637) William Piso as physician, and early in 1638 was joined by George Marcgrave who had been sent out from Holland as astronomer and geographer. Piso gave attention to minerals and the medical history of Brazil, and Marcgrave to observations on astronomy and, what interests us the most, to the plants and animals of the same country. After the death of Marcgrave (1644) the manuscripts of Piso and Marcgrave were prepared for the printer by de Laet, an officer of the Dutch West India Company, and were published in 1648[10] in a folio volume of two parts. The first part contained Piso's, the second Marcgrave's contribution. We disregard Piso's part as not being connected directly with our subject.

George Marcgrave (1610–1644) was an excellent observer

[9] For an account of the various zoölogical acquisitions from voyages to India, South America, Mexico and Africa, see Carus: *Geschichte der Zoölogie*, or its French translation, pp. 255, *et suiv.*

[10] Guil. Piso, *Historia naturalis Brasiliæ, De medicina Brasiliensi*, libri IV, et Georgi Marcgravi, *Historiæ rerum naturalium Brasiliæ*, libri VIII, etc., Joa. de Laert, in ordinem digessit. Lugd. Bat, 1648.

with a varied university training in astronomy, botany, mathematics and medicine. On arriving in Brazil (near Pernambuco) he worked devotedly on astronomy and made some of the earliest observations on the stars of the southern hemisphere. At the same time he made several excursions for the collection and observation of plants and animals of the region and worked with great intensity as a naturalist. He improved the earlier descriptions of plants and animals already known from that part of the world, and described and illustrated a large number that were new to science. His descriptions were carefully made from life and most of them were illustrated by good water-color sketches made by his own hand, but rendered less exact and accurate in the woodcuts.

The first edition of the work mentioned above gives Marcgrave's own descriptions, translated from the cipher in which they were first written (as a protection against the devious acquisitiveness of Piso). In a second edition published by Piso, in 1658 after the death of de Laet, Marcgrave's work is mutilated and much of it is claimed by Piso as his own. In de Laet's edition of 1648 the work of Marcgrave (including preface, etc.) occupies three hundred three folio pages. It embraces descriptions of three hundred one plants illustrated by two hundred sketches, and three hundred sixty-seven animals with two hundred twenty-two pictures, this makes a total of six hundred sixty-eight descriptions with four hundred twenty-two illustrations. A large number of the animals and plants were described for the first time and most of the excellent colored illustrations represented forms that had never been sketched before. We get a new light on the claims of Marcgrave to remembrance when we consider that the text and illustrations were original at a time when compilation was the rule. His treatment of aquatic animals includes fishes, crustacea, the starfish, etc. In addition to the aquatic animals his treatise contains descriptions and sketches of mammals, birds, serpents, and insects. Although he enjoyed considerable recognition as an authority and some of his sketches were copied by Ray and others, his treatise was on

exotic forms, and the more popular works of Gesner and Aldrovandi which dealt comprehensively with local and foreign animals, still held the attention of the public. It may be said in general that special treatises on natural history such as Marcgrave's — of which there was a considerable number in the sixteenth and seventeenth centuries — did not have the influence on the progress of natural history of the more comprehensive treatises. Marcgrave's work was practically lost sight of for one hundred fifty years and did not receive the general recognition of which it was deserving. It is only during recent years that the high quality of his descriptions has begun to be appreciated.[11]

RAY AND WILLUGHBY

John Ray, the English forerunner of Linnæus, building on the foundations of Gesner and Aldrovandi, raised the natural-history edifice a tier higher. By discarding the irrelevancies of these earlier writers he reduced the bulk of books on natural history, and by introducing anatomy as a descriptive feature for larger groups he imparted a more modern tone to scientific writings. He was the son of a blacksmith and was born in 1628 at Black Notley in southern England. On going to the University of Cambridge, where he first entered Catherine Hall and later Trinity College, he changed the spelling of his name to Wray. It appears in that form on the college records and on the title page of some of his early publications; in 1670 he abandoned this usage and reverted to the spelling Ray. He was graduated at the University of Cambridge in 1649 and became a fellow of Trinity College; from that date for a period of thirteen years, he held various college appointments: lecturer in Greek, mathematics, humanity, junior dean, and college steward. His reputation as a tutor was high, and having a passion for observation of nature's productions, he gathered about him a small group of students for the study of animals and plants by field excursions. Among them was Francis Willughby, a young man of

[11] See E. W. Gudger: *George Marcgrave, the First Student of American Natural History*, Pop. Sci. Monthly, September, 1912.

wealth, whose interest in the study of animals was very intense. Tutor and pupil became fast friends and their association proved a happy one for both parties.

Ray was an eloquent speaker and as was the custom, he delivered sermons in the chapel of his own college and also be-

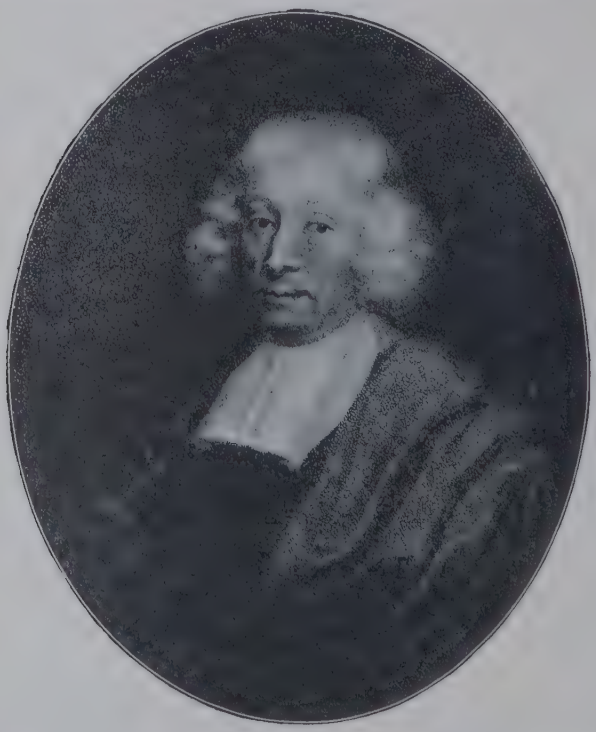

FIG. 94. — JOHN RAY, 1628–1705. (Published by Dr. Thornton, 1804.)

fore the university at Great St. Mary's long before he took holy orders. Two of his discourses became very famous: *The Wisdom of God Manifested in the Works of Creation*, and *Chaos, Deluge and Dissolution of the World*. In 1660 Ray was ordained both deacon and priest of the Church of England and thereafter held his university position as a cleric, but from conscientious scruples

he resigned his fellowship in 1662. He was now thirty-four years of age, and, as mentioned above, had served in college and university life for thirteen years.

For the next ten years, except when absent on scientific travels, he lived at Middleton Hall, the county seat of Willughby, receiving financial emolument as well as his living. The two men united in a project of collecting materials and writing books on animals and plants; at Willughby's expense they traveled extensively in Great Britain and on the Continent, with a view of investigating the natural history of the places visited. On these excursions Willughby gave especial attention to animals and Ray to plants. Ray's extensive contributions to botany will be spoken of later as a feature in botanical progress, and now we follow especially his connection with Willughby's manuscripts and his own publications on animals.

FIG. 95. — FRANCIS WILLUGHBY, 1635–1672. (Jardine, *The Naturalist's Library*.)

Willughby died in 1672, at the age of thirty-eight, leaving an annuity to Ray and charging him with the education of his two sons. Ray performed these charges with a single devotion and in a generous spirit. He edited and published Willughby's book on birds (1676). The descriptions of individual birds had been made with meticulous care and directly from the animals — among other points they included a record of measurements and weights. By his own inclination Ray would have been more direct and brief in the descriptions, but he felt constrained to publish all that Willughby had written. In his preface to the book on birds he remarks: "Now though I cannot but commend

his diligence, yet I must confess that in describing the colors of each single feather he sometimes seems to me to be too scrupulous and particular . . . yet dared I not to omit or alter anything.[12] There is a tradition that Willughby left ill-digested manuscripts and there is little doubt that Ray improved the text before it was printed. To what extent he may have added matter of his own is uncertain. He gave all the credit to Willughby and probably it belonged there.

After the death of Willughby's mother in 1676, conditions were altered at Middleton Hall and Ray with his wife removed to a nearby village and, finally, in 1679, they went to live at Black Notley where Ray had been born. Here, depending for support almost entirely on the small stipend [13] bequeathed by Willughby, he devoted himself to completing his task as the literary executor of his patron and to preparing works of his own. In 1686 he brought out Willughby's book on fishes, the expense of its publication being met by certain members of the Royal Society. Through his collecting trips and subsequent studies, Ray had accumulated a vast amount of original observations and showed great industry in preparing them for the press. In 1682 appeared his famous *Methodus* proposing a new classification of plants and in 1686–1704 his comprehensive *Historia plantarum* in three volumes. His botanical work gave him an honorable place in the history of botany. But he had also made extensive observations on animals and in 1693 published a work on quadrupeds and serpents which give him high place in the history of the classification of animals.[14]

In 1691 appeared in print *The Wisdom of God Manifested in the Creation,* and the following year *Chaos, the Deluge and Dissolution of the World.* These books were amplifications of ser-

[12] Miall, *The Early Naturalists,* p. 103.

[13] At first sixty pounds, which was slightly increased and continued to Ray for life.

[14] Ray also wrote a *History of Insects,* using Willughby's notes and adding many of his own observations. It was published in 1710. The work is of minor importance, scarcely an improvement on Moffett's (1634) and completely thrown into the shade by Swammerdam's.

mons, which, as mentioned before, were preached many years earlier at the University of Cambridge. The "Wisdom of God" was extensively read and became very popular; it passed through many editions and was translated into several languages. In it he gave many examples of purposive adaptations and of design in nature. It was a forerunner of works like Paley's *Natural Theology*, a book which became celebrated from the last of the eighteenth to the middle of the nineteenth century.

After an honorable, upright, productive life, he passed away in 1705, at the age of seventy-seven. The eminence of his work was recognized by later generations, and in 1844 there was founded in London, in his memory, the *Ray Society* for the publication of rare and important works in botany and zoölogy.

Ray's Idea of Species. Ray was the first to introduce into natural history a precise conception of species. Before his time the word had been used by naturalists in an indefinite sense, and often to include groups of animals and plants of greater or less extent, but Ray applied it singly to individuals derived from similar parents and themselves capable of reproducing their kind. The term was removed from the category of a logical distinction and made to stand for an individual kind of animal or plant. In the light of subsequent development this was a distinction of great theoretical importance; from it arose the dogma of the constancy of species. We should note, however, that Ray did not assign to the species that unvarying and constant character ascribed to it by Linnæus and his followers. He observed some variation among species and in his *Historia plantarum* devotes a chapter to the consideration of their variability. He remarks that the sign of specific identity is not always constant and infallible, and that experience shows us that it is possible, although rare, for a seed to give rise to an individual different from the parent.[15] Although his definition of

[15] The original passage exhibits the impartial tone of Ray. "Verum nota hæc quamvis constans sit specificæ convenientiæ signum, non tamen perpetuum est et infallible. Semina enim nonnulla degenerare et diversæ a matre speciei plantas interdum licet rarius producere adeoque dari in plantis transmutationem specierum experimenta evincunt." *Hist. plant.* Tomus 1, p. 42.

species occurs in his history of plants he applies it to animals as well. Ray also made use of anatomy as the foundation for zoölogical classification, and introduced great precision and clearness into his definitions of groups of animals and plants. In the particulars mentioned he represents a great advance beyond any of his precursors, and marks the parting of the ways between the old natural history and the beginning of a new era in which Linnæus was the central figure.

LINNÆUS OR LINNÉ

Linnæus was both botanist and zoölogist; we cannot sharply distinguish between his contributions to botany and zoölogy, but in this chapter we deal chiefly with his general influence and with his zoölogical work, reserving for a following chapter an account of his work in botany. His service to natural history was unique. The large number of specimens of animals and plants, ever increasing through the collections of travelers and naturalists, were in a confused state, and there was great ambiguity arising from the lack of a methodical way of arranging and naming them. They were known by verbose descriptions and local names. No scheme had as yet been adopted for securing uniformity in applying names to them. The same animal and plant had different names in the different sections of a country, and often different plants and animals had the same name. In different countries, also, their names were greatly diversified. What was especially needed was some great organizing mind to catalogue the animals and plants in a systematic way, and to give to natural science a common language. Linnæus possessed this methodizing mind and supplied the need. While he did little to deepen the knowledge of the organization of animal and plant life, he did much to extend the number of known forms; he simplified the problem of cataloguing them, and he proposed a simple method of naming them which was adopted throughout the world. By a happy stroke he gave to biology a new scientific terminology that remains in use today. The tremendous influence of this may be realized when we

remember that naturalists everywhere use identical names for the same animals and plants. Latin, which for centuries had been the language of scholars in western Europe, was adopted as the medium of expression, and today, as was just said, naturalists of the most distant countries employ the same Latin names in classifying organic forms.

He also inspired many students with a love for natural history and gave an impulse to the advance of that science which was long felt. We cannot deny that a higher class of service has been rendered by those of philosophic mind devoted to the pursuit of comparative anatomy, but the step of Linnæus was a necessary one, and aided greatly in the progress of natural history. Without this step the discoveries and observations of others would not have been so readily understood, and had it not been for his organizing force all natural science would have been held back for want of a common language. A close scrutiny of the practice among naturalists in the time of Linnæus shows that he did not actually invent the binomial nomenclature, but by adopting the suggestions of others he elaborated the system of classification and brought the new language into common use.

There were anticipations of the scientific terminology of Linnæus; as we have seen, Caspar Bauhin in his *Pinax* (1623) had used a binomial nomenclature for naming plants. One of Linnæus' immediate predecessors, Jacob Friedrich Klein, had struggled with the question of recognizing genera and species and of giving scientific names to them. His conception of species was far below that of Ray, he considered it merely as a unit of classification — as the smallest systematic group of animals and plants. Klein said that the Creator had divided animals into genera and species and the aim of zoölogy was to discover and formulate their characters. His classification was more like a system of logic than a recognition of the individuality of species. His studies were extensive but they lacked the clear analysis of Linnæus. Nevertheless, had it not been overshadowed by that of Linnæus, his system would have received

greater recognition as a step towards the formulation of a scientific terminology.

Personal History. Leaving for the present the system of Linnæus, we shall give attention to the personal history of the man. The great Swedish naturalist was born in Rashult in 1707. His father was the pastor of the village, and intended his eldest son, Carl, for the same high calling. The original family name was Ignomarsen, but it had been changed to Lindelius, after a tall linden-tree growing in that part of the country. In 1761 a patent of nobility was granted by the crown to Linnæus, and thereafter he was styled Carl von Linné.

His father's resources were very limited, but he managed to send his son to school, though it must be confessed that young Linnæus showed little liking for the ordinary branches of instruction. He spent most of his time in collecting natural-history specimens, and his mind was engaged in thinking about them. The reports of his low scholarship and the statement of one of his teachers that he showed no aptitude for learning were so disappointing to his father that, in 1726, he prepared to apprentice Carl to a shoemaker, but was prevented from doing so through the encouragement of a doctor who, being able to appreciate the quality of mind possessed by the young Linnæus, advised allowing him to study medicine instead of preparing for theology.

Accordingly, with a sum amounting to about $40, all his father could spare, he set off for the University of Lund, to pursue the study of medicine. He soon transferred to the University of Upsala, and it was not until eight years later, in 1735, that he received his degree in Holland.

At Upsala he was relieved from his extreme poverty by obtaining an assistant's position, and so great was his knowledge of plants that he was delegated to read the lectures of Rudbeck, the aged professor of botany.

In 1732 he was chosen by the Academy of Sciences of Upsala to visit Lapland as a collector and observer, and left the university without his degree. On returning to Upsala, his lack

of funds made itself again painfully felt, and he undertook to support himself by giving public lectures on botany, chemistry, and mineralogy. He secured hearers, but the continuance of his lectures was prevented by one of his rivals on the ground that Linnæus had no degree, and was therefore legally disqualified from taking pay for instruction. Presently he became tutor and traveling companion of a wealthy baron, the governor of the province of Dalecarlia, but this employment was temporary.

Helped by His Fiancée. His friends advised him to secure his medical degree and settle as a practitioner. Although he lacked the necessary funds, one circumstance contributed to bring about this end; he had formed an attachment for the daughter of a wealthy physician, named Moré or Moræus, and on applying for her hand in marriage, her father made it a condition of his consent that Linnæus should take his medical degree and establish himself in the practice of medicine. The young lady, who was thrifty as well as handsome, offered her savings, amounting to one hundred dollars (Swedish) to her lover. He succeeded in adding to this sum by his own exertions, and with thirty-six Swedish ducats set off for Holland to qualify for his degree. He had practically met the requirements for the medical degree by his previous studies, and after a month's residence at the University of Harderwyk,[16] his thesis was accepted and he was granted the degree in June, 1735, in the twenty-eighth year of his age.

Instead of returning at once to Sweden, he went to Leyden, and made the acquaintance of several well-known scientific men. He continued his botanical studies with great energy, and now began to reap the benefits of his earlier devotion to natural history.

Through the influence of Boerhaave, Linnæus became the medical attendant of Cliffort, the burgomaster at Amsterdam, who had a large botanic garden. Cliffort, being desirous of extending his collections, sent Linnæus to England, where he met Sir Hans Sloane and other eminent scientific men of Great

[16] The Athenæum of Harderwyk founded 1603, closed in 1811.

Britain. After a short period he returned to Holland, and in 1737 brought out the *Genera plantarum,* a very original work, containing an analysis of all the genera of plants. He had previously published, besides the *Systema naturæ,* his *Fundamenta botanica,* 1735, and *Bibliotheca botanica,* 1736, and these works served to spread his fame as a botanist throughout Europe.

His Wide Recognition. An illustration of his wide recognition is afforded by an anecdote of his first visit to Paris in 1738. "On his arrival he went first to the Garden of Plants, where Bernard de Jussieu was describing some exotics in Latin. He entered without opportunity to introduce himself. There was one plant which the demonstrator had not yet determined, and which seemed to puzzle him. The Swede looked on in silence, but observing the hestitation of the learned professor, cried out 'Haec planta faciem Americanam habet.' 'It has the appearance of an American plant.' Jussieu, surprised, turned about quickly and exclaimed 'You are Linnæus.' 'I am, sir,' was the reply. The lecture was stopped, and Bernard gave the learned stranger an affectionate welcome."

Return to Sweden. After an absence of three and one-half years, Linnæus returned to his native country in 1738, and soon after was married to the young woman who had assisted him and had waited for him so loyally. He settled in Stockholm and began the practice of medicine. In the period of his absence he had accomplished much: visited Holland, England, and France, formed the acquaintance of many eminent naturalists, obtained his medical degree, published numerous works on botany, and extended his fame over all Europe. In Stockholm, however, he was for a time neglected, and he would have left his native country in disgust had it not been for the dissuasion of his wife.

Professor in Upsala. In 1741 he was elected professor of anatomy in the University of Upsala, but by a happy stroke was able to exchange that position for the professorship of

botany, materia medica, and natural history that had fallen to his former rival, Rosen. Linnæus was now in his proper element; he had opportunity to lecture on those subjects to which he had been devotedly attached all his life, and he entered upon the work with enthusiasm.

He attracted numerous students by his genial personality and the excellence of his lectures. He became the most popular professor in the University of Upsula, and, owing to his drawing power, the attendance at the university was greatly increased. In 1749 he had one hundred forty students devoted to studies in natural history. The number of students at the university had been about five hundred; "whilst he occupied the chair of botany there it rose to fifteen hundred." A part of this increase was due to other causes, but Linnæus was the greatest single drawing force in the university. He was an eloquent as well as an enthusiastic lecturer, he aroused great interest among his students, and he gave an astounding impulse to the study of natural history in general, and to botany in particular. Thus Linnæus, after having passed through great privations in his earlier years, found himself, at the age of thirty-four established in a position which brought him recognition, honor, and large emolument.

Personal Appearance. The portrait of Linnæus at the age of sixty is shown in Fig. 96. He was described as of "medium height, with large limbs, brown, piercing eyes, and acute vision." His hair in early youth was nearly white, changed in his manhood to brown, and became gray with the advance of age. Although quick-tempered, he was naturally of a kindly disposition, and secured the affection of his students, with whom he associated and worked in the most informal way. His love of approbation was very marked, and he was so much praised that his desire for fame became his dominant passion. The criticism to which his work was subjected from time to time accordingly threw him into fits of despondency and rage.

In May, 1907, the University of Upsala celebrated the two hundredth anniversary of his birth with appropriate ceremonies.

Delegations of scientific men from all over the world were in attendance to do honor to the memory of the great founder of biological nomenclature.

The Systema Naturæ. When Linnæus received his medical degree from the "University" of Harderwyk in 1735 he was

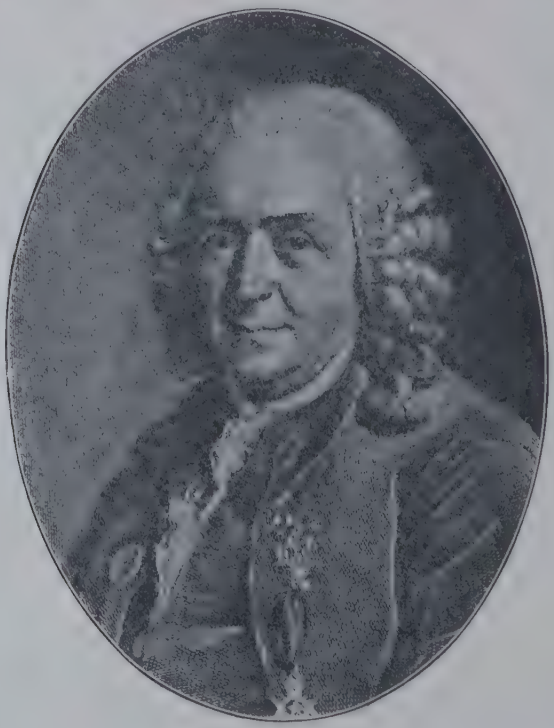

Fig. 96. — Linnæus at Sixty.

twenty-eight years of age; but for eight or nine years previous to this he had been a zealous student. By travel, exploration, teaching, and intensive application to the study of animals and plants, he was already an accomplished naturalist. He now went to Leyden carrying with him the manuscript of the *Systema naturæ*, and with the encouragement of his new friends it was

published in the same year. The first edition (1735) of that notable work, which was afterward to bring him so much fame, consisted of twelve printed folio pages. It was merely an outline of the arrangements of plants, animals, and minerals in a methodical catalogue. This work passed through twelve editions during his lifetime, the last one appearing in 1768. After the first edition, the books were printed in octavo form, and in the later editions were greatly enlarged. A copy of the first edition was sent to Boerhaave, the most distinguished professor in the University of Leyden, and secured for Linnæus an interview with that distinguished physician, who treated him with consideration and encouraged him in his work.

In his *Systema naturæ* and in other publications he employed a means of naming every natural production in two words, and it is therefore called the binomial nomenclature. An illustration will make this clearer. Those animals which had close resemblance, like the lion, tiger, leopard, the lynx, and the cat, he united under the common generic name of Felis, and gave to each a particular trivial name, or specific name. Thus the name of the lion became Felis leo, of the tiger Felis tigris, of the leopard Felis pardus, of the cat Felis catus; etc. In a similar way, the dog-like animals were united into a genus designated Canis, and the particular kinds or species became Canis lupus, the wolf; Canis vulpes, the fox; Canis familiaris, the common dog; etc. This simple method took the place of the varying names applied to the same animal in different countries and local names in the same country. It recognized at once their generic likeness and their specific individuality.

All animals, plants, and minerals were named according to this method. Thus there were introduced into nomenclature two groups, the genus and the species. The name of the genus was a noun, and that of the species an adjective agreeing with it. In the choice of these names Linnæus sought to express some distinguishing feature that would be suggestive of the particular animal, plant or mineral. The trivial, or specific, names were first employed by Linnæus in 1749, and were introduced into his

Species plantarum in 1753, and into the tenth edition of his *Systema naturæ* in 1758.

The *Systema naturæ* is not a treatise on the organization of animals and plants; it is rather a catalogue of the productions of nature methodically arranged. His aim in fact was not to give full descriptions, but to make a methodical arrangement.

To do justice, however, to the discernment of Linnæus, it should be added that he was fully aware of the artificial nature of his classification. As Kerner has said: "It is not the fault of this accomplished and renowned naturalist if a greater importance were attached to his system than he himself ever intended. Linnæus never regarded his twenty-four classes as real and natural divisions of the vegetable kingdom, and specifically says so; it was constructed for convenience of reference and identification of species. A real natural system, founded on the true affinities of plants as indicated by the structural characters, he regarded as the highest aim of botanical endeavor. He never completed a natural system, leaving only a fragment (published in 1738)."

We recognize Linnæus as the founder of nomenclature in natural history, and by the common consent of naturalists the date 1758 has come to be accepted as the starting-point for determining the generic and specific names of animals. The much vexed question of priority of names for animals is settled by going back to the tenth edition of his *Systema naturæ,* while the botanists have adopted his *Species plantarum,* 1753, as their baseline for names. As to his larger divisions of animals and plants, he recognized classes and orders. Then came genera and species. Linnæus did not use the term family in his formulæ; this convenient designation was first used and introduced in 1780 by Batch.

His Influence upon Natural History. However much we may admire the industry and force of Linnæus, we must admit that he gave to natural history a one-sided development, in which the more essential parts of the science received scant recognition. His students, like their master, were mainly collectors and classifiers. "In their zeal for naming and classifying, the higher

goal of investigation, knowledge of the nature of animals and plants, was lost sight of and the interest in anatomy, physiology, and embryology lagged."

R. Hertwig says of him: " For while he in his *Systema naturæ* treated of an extraordinarily larger number of animals than any earlier naturalist, he brought about no deepening of our knowledge. The manner in which he divided the animal kingdom, in comparison with the Aristotelian system, is to be called rather a retrogression than an advance. Linnæus divided the animal kingdom into six classes — Mammalia, Aves, Amphibia, Pisces, Insecta, Vermes. The first four classes correspond to Aristotle's four groups of animals with blood. In the division of the invertebrated animals into Insecta and Vermes Linnæus stands undoubtedly behind Aristotle, who attempted, and in part indeed successfully, to set up a larger number of groups.

" But in his successors even more than in Linnæus himself we see the damage wrought by the purely systematic method of consideration. The diagnoses of Linnæus were for the most part models, which, *mutatis mutandis,* could be employed for new species with little trouble. There was needed only some exchanging of adjectives to express the differences. With the hundreds of thousands of different species of animals, there was no lack of material, and so the arena was opened for that spiritless zoölogy of species-making, which in the first half of the nineteenth century brought zoölogy into such discredit. Zoölogy would have been in danger of growing into a Tower of Babel of species-description if a counterpoise had not been created in the strengthening of the physiologico-anatomical method of consideration."

His Especial Service. Nevertheless, the work of Linnæus made a lasting impression upon natural history, and we shall do well to get clearly in mind the nature of his particular service. In the first place, he brought into use the method of naming animals and plants which is employed today. A second feature of his work is terseness of the language employed. His descriptions were marked by extreme brevity, but by great clearness.

In giving the diagnosis of a form he did not employ fully formed sentences containing a verb, but words concisely put together so as to bring out the chief things he wished to emphasize. As an illustration of this, we may take his characterization of the forest rose, "Rosa sylvestris vulgaris, flore odorata incarnato." The common rose of the forest with a flesh-colored, sweet-smelling flower. In thus fixing the attention upon essential points he got rid of verbiage, a step that was of very great importance.

A third feature of his work was that of emphasizing the idea of species. In this he built upon the work of Ray. We have already seen that Ray was the first to define species and to bring the conception into natural history. Ray had spoken of the variability of species, but Linnæus, in his earlier publications, declared that they were constant and invariable. His conception of a species was that of individuals born from similar parents. It was assumed that at the original stocking of the earth, one pair of each kind of animals was created, and that existing species were the direct descendants without change of form or habit from the original pair. As to their number, he said: "Species tot sunt, quot formæ ab initio creatæ sunt" — there are just so many species as there were forms created in the beginning; and his oft-quoted remark, "Nullæ species novæ" indicates in terse language his position as to the formation of new species. Linnæus took up this idea as expressing the current thought, without analysis of what was involved in it. He readily might have seen that if there were but a single pair of each kind, some of them must have been sacrificed to the hunger of the carnivorous kinds; but, better than making any theories, he might have looked for evidence in nature as to the fixity of species.

While Linnæus first pronounced upon the fixity of species, it is interesting to note that his extended observations upon nature led him to see that variation among animals and plants is common and extensive, and accordingly in the later editions of his *Systema naturæ* we find him receding from the position that species are fixed and constant. Nevertheless, it was owing

to his influence, more than to that of any other writer of the period, that the dogma of fixity of species was established. His great contemporary Buffon looked upon species as not having a fixed reality in nature, but as being figments of the imagination; and we shall see in a later section of this book how the idea of Linnæus in reference to the fixity of species gave way to accumulating evidence on the matter.

SUMMARY

The chief services of Linnæus to natural science consisted of three things: bringing into current use the binomial nomenclature, the introduction of terse formulæ for description, and fixing attention upon species. The first two were necessary steps; they introduced clearness and order into the management of the immense number of details, and they made it possible for the observations and discoveries of others to be understood and to take their place in the great system of which he was the originator. The effect of the last step was to direct the attention of naturalists to species, and thereby to pave the way for the coming consideration of their origin, a consideration which became such a burning question in the last half of the nineteenth century.

CHAPTER XV

REFORM OF THE LINNÆAN CLASSIFICATION OF ANIMALS

As indicated in the preceding chapters, the classification established by Linnæus had grave defects; it was not founded on a knowledge of the comparative structure of animals and plants, but in many instances upon superficial features that were not distinctive in determining their position and relationships. His system was essentially an artificial one, a convenient key for finding the names of animals and plants, but doing violence to the natural arrangement of those organisms. An illustration of this is seen in his classification of plants into classes mainly on the basis of the number of stamens in the flower, and into orders according to the number of pistils. Moreover, the true object of investigation was obscured by the Linnæan system. The chief aim of biological study being to extend our knowledge of the structure, development, and physiology of animals and plants as a means of understanding more about their life, the arrangement of animals and plants into groups should be the outcome of such studies rather than an end in itself.

It was necessary to follow different methods to bring natural history back into the line of true progress. The first modification of importance to the Linnæan system was that of Cuvier, who proposed a grouping of animals based upon a knowledge of their comparative anatomy. He declared that animals exhibit four types of organization, and his types were substituted for the primary groups of Linnæus.

THE SCALE OF BEING

In order to understand the bearing of Cuvier's conclusions we must take note of certain views regarding the animal kingdom

that were generally accepted at the time of his writing. Between Linnæus and Cuvier there had emerged the idea that all animals, from the lowest to the highest, form a graduated series. This grouping of animals into a linear arrangement was called exposing the Scale of Being, or the Scale of Nature (Scala naturæ). Buffon, Lamarck, and Bonnet were among the chief exponents of this idea.

That Lamarck's connection with it was temporary has been generally overlooked. It is the usual statement in the histories of natural science, as in the *Encyclopædia Britannica,* in the History of Carus, and in Thomson's Science of Life, that the idea of the scale of nature found its fullest expression in Lamarck. Thomson says: "His classification (1801–1812) represents the climax of the attempt to arrange the groups of animals in linear order from lower to higher, in what was called a Scala naturæ." [1] Richard Hertwig and E. Ray Lankester have expressed the matter in a similar form. Now, while Lamarck adopted a linear classification in his earlier writings, it is only a partial reading of his works that will support the conclusion that he held to it. In his *Système des Animaux sans Vertèbres,* published in 1801, he arranged animals in this way; but to do credit to his discernment, it should be observed that he was the first to employ a genealogical tree (Fig. 97) and to break up the serial arrangement of animal forms. In 1809, in the second volume of his *Philosophie Zoölogique,* as Packard has pointed out, he arranged animals according to their relationships, in the form of a trunk with divergent branches. This was no vague suggestion on his part, but an actual pictorial representation of the relationship between different groups of animals as conceived by him. Although a crude attempt, it is interesting as being the first of its kind. This arrangement is so directly opposed to the idea of Scale of Being that we should make note of the fact that Lamarck forsook that view twenty years before the close of his life at least, and substituted for it that of the genealogical tree.

[1] *The Science of Life,* p. 14.

LAMARCK'S POSITION IN SCIENCE

Lamarck is coming into full recognition for his part in founding the evolution theory, but he is not generally, as yet, given

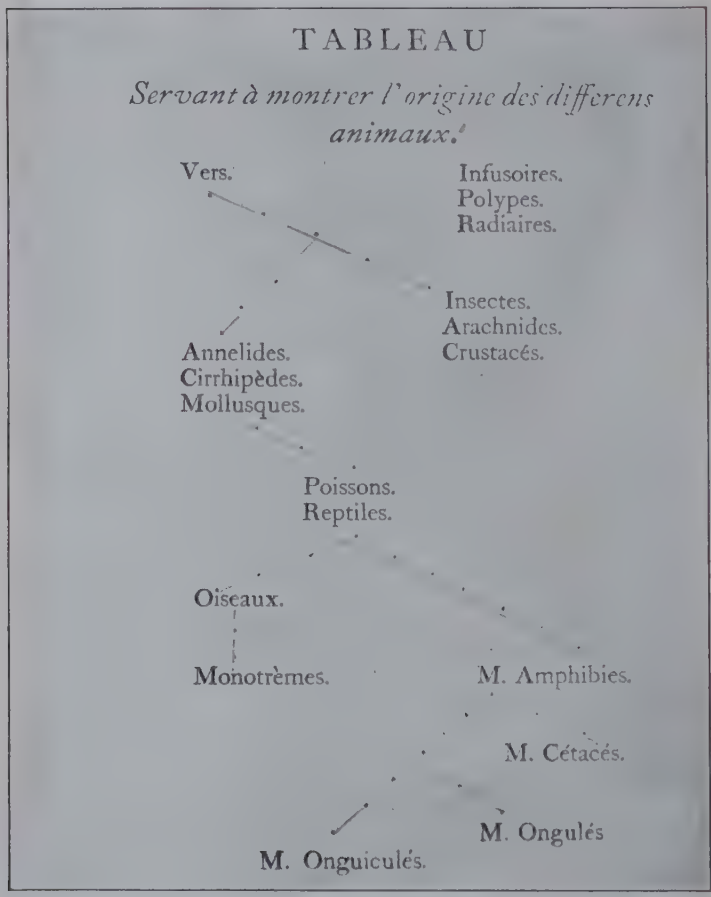

FIG. 97. — LAMARCK'S SKETCH OF THE GENEALOGICAL TREE OF ANIMALS. (*Philosophie zoölogique*, 1809. After A. S. Packard.)

due credit for his work in zoölogy. He was the most philosophical thinker engaged with zoölogy at the close of the eight-

eenth and the beginning of the nineteenth century. He was greater than Cuvier in his reach of intellect and in his discernment of the true relationships among living organisms. We are to recollect that he forsook the dogma of fixity of species, to which Cuvier held, and founded the first comprehensive theory of organic evolution. Today we can recognize the superiority of his mental grasp over that of Cuvier, but, owing to the personal magnetism of the latter and to his position, the ideas of Lamarck, which Cuvier combated, received but little attention when they were promulgated. We shall have occasion in a later chapter to speak more fully of Lamarck's contribution to the progress of biological thought.

CUVIER'S FOUR BRANCHES

We now return to the type-theory of Cuvier. By extended studies in comparative anatomy, he came to the conclusion that animals are constructed upon four distinct plans or types: the vertebrate type; the molluscan type; the articulated type, embracing animals with joints or segments; and the radiated type, the last with a radial arrangement of parts, like the starfish, etc. These types are distinct, but their representatives, instead of forming a linear series, overlap, so that the lowest forms of one of the higher groups are simpler in organization than the higher forms of a lower group. This was very illuminating, and, being founded upon an analysis of structure, was important. It was directly at variance with the idea of scale of being, and overthrew that doctrine.

Cuvier first expressed these views in a pamphlet published in 1795, and later in a better-known paper read before the French Academy in 1812, but for the full development of his type-theory we look to his great volume on the animal kingdom published in 1816. The central idea of his arrangement is contained in the secondary title of his book, "The Animal Kingdom Arranged According to its Organization" (Le Règne Animal Distribué d'après son Organisation, 1816). The expression "arranged according to its organization" embraces the feature

in which this analysis of animals differs from all previous attempts.

Correlation of Parts. An important idea, first clearly expressed by Cuvier, was that of correlation of parts. The view is that the different parts of an animal are so correlated that a change in one, brought about through changes in use, involves a change in another. For illustration, the cleft hoof is always associated with certain forms of teeth and with the stomach of a ruminant. The sharp claws of flesh-eating animals are associated with sharp, cutting teeth for tearing the flesh of the victims, and with an alimentary tube adapted to the digestion of a fleshy diet. Further account of Cuvier is reserved for the chapter on the Rise of Comparative Anatomy, of which he was the founder.

VON BAER

The next notable advance affecting natural history came through the work of Von Baer, who, in 1828, founded the science of development of animal forms. He arrived at substantially the same conclusions as Cuvier. Thus the system founded upon comparative anatomy by Cuvier came to have the support of Von Baer's studies in embryology.

The contributions of these men proved to be a turning-point in natural history, and subsequent progress in systematic botany and zoölogy resulted from the application of the methods of Cuvier and Von Baer, rather than from following that of Linnæus. His nomenclature remained a permanent contribution of value, but the knowledge of the nature of living forms has been advanced chiefly by studies in comparative anatomy and embryology, and, also, in the application of experiments.

The most significant advances in reference to the classification of animals was to come as a result of the acceptance of the doctrine of organic evolution, subsequent to 1859. Then the relationships between animals were made to depend upon community of descent, and a distinction was drawn between superficial or apparent relationships and those deep-seated characteristics that depend upon close genetic affinities.

ALTERATIONS BY VON SIEBOLD AND LEUCKART

But, in the meantime, naturalists were not long in discovering that the primary divisions established by Cuvier were not well balanced, and, indeed, that they were not natural divisions of the animal kingdom. At this time there arose in Germany a

Fig. 98. — Karl Th. von Siebold, 1804–1885.

strong man in zoölogical science — Karl Theodor von Siebold. (Fig. 98). He was educated in science and medicine chiefly at the University of Berlin and became successively professor of zoölogy, physiology, and comparative anatomy in Königsberg,

Erlangen, Freiburg, Breslau, and Munich. He played a considerable part in the progress of zoölogy, especially in reference to the comparative anatomy of invertebrates. Besides his special researches, his textbook on the invertebrates [2] (1845) was a landmark in the production of better textbooks for university teaching. It was the best textbook on invertebrates before the Darwinian era; its translation into English spread his influence to England and the United States. Von Siebold is remembered by zoölogists as the founder (in conjunction with Kölliker) of a famous Journal of Scientific Zoölogy (Zeitschrift für wissenschaftliche Zoölogie).

In Cuvier's classification the group Radiata was the least sharply defined, since he had included in it not only those animals which exhibit a radial arrangement of parts, but also unicellular organisms that were asymmetrical, and some of the worms that showed bilateral symmetry. Accordingly, von Siebold, in 1845, separated these animals and redistributed them. For the simplest unicellular animals he adopted the name Protozoa, which they still retain, and the truly radiated forms, as starfish, sea-urchins, hydroid polyps, coral animals, etc., were united in the group Zoöphyta. Von Siebold also changed Cuvier's branch, Articulata, separating those forms such as crustacea, insects, spiders, and myriapods, which have jointed appendages, into a natural group called Arthropoda, and uniting the segmented worms with those worms that Cuvier had included in the radiate group, into another branch called Vermes. This separation of the four original branches of Cuvier was a movement in the right direction, and was destined to be carried still farther.

Rudolph Leuckart (Fig. 99), a more highly gifted man than von Siebold, made further modifications. After 1860 his fame as a lecturer and teacher attracted many young men from Germany and foreign countries to the University of Leipzig; it is perhaps not an exaggeration to say that he had the training of more naturalists of distinction than any other teacher of Europe.

[2] *Lehrbuch der vergleichenden Anatomie*, by Von Siebold and Stannius, 1845–1848. Stannius prepared the part of the vertebrates.

He split von Siebold's group of Zoöphytes into two distinct kinds of radiated animals: the starfishes, sea-urchins, sea-cucumbers, etc., having a spiny skin, he designated Echinoderma; the jelly-fishes, polyps, coral animals, etc., not possessing a true body

Fig. 99. — Rudolph Leuckart, 1823–1898.

cavity, were also united into a natural group, for which he proposed the name Cœlenterata.

From all these changes there resulted the seven primary divisions — subkingdoms, or phyla — which, with small modifications are still in use. These are Protozoa, Cœlenterata, Echinoderma, Vermes, Arthropoda, Mollusca, Vertebrata. All zoölogists recognize that these seven phyla are not sufficient, and there has been carried forward a redistribution of animals and the formation of additional phyla. Except for the necessary suppression of the old phylum Vermes, and the distribution of

its representatives into three separate phyla, the changes are of more narrow compass than the alterations of von Siebold and Leuckart. The tabulation given below will be helpful in picturing to the mind the modifications made in the large groups from Linnæus to Leuckart.

Linnæus	*Cuvier*	*Von Siebold*	*Leuckart*
Mammalia	Vertebrata (Embracing five classes: Mammalia, Aves, Reptilia, Batrachia, Pisces.)	Vertebrata (Embracing five classes.)	Vertebrata (Five classes.)
Aves			
Amphibia			
Pisces			
Insecta Including Crustacea, etc.)	Mollusca	Mollusca	Mollusca
	Articulata	Arthropoda	Arthropoda
		Vermes	
Vermes (Including Mollusca and all lower forms.)		Vermes	Vermes
	Radiata	Zoöphyta	Echinoderma
			Cœlenterata
		Protozoa	Protozoa

SUMMARY

In reviewing the rise of systematic zoölogy (systematic botany has a similar history), we see a development of the subject extending over centuries, first through a return to Aristotle, through gradual additions to his observations — notably by Gesner — and then, the striking additions due to Ray and Linnæus. We may speak of these two naturalists as the founders of systematic botany and zoölogy. But the system left by Linnæus was highly artificial, and the great obvious need was to convert it into a natural system founded upon a knowledge of the structure and development of living organisms. This was begun by Cuvier and Von Baer, and was continued especially by von Siebold and Leuckart. Linnæus emphasized that phase of zoölogy that has for its aim to give a descriptive inventory of the animal kingdom. We should remember, however, that this is merely one aspect of zoölogy. In early times it was made the dominant feature, but it is subordinate in importance to those phases of the subject that deal with structure, development, physiology, habits, etc. In-

deed, the orderly arrangement of animals into natural groups should be an outcome of the study of their structure and life histories.

Ever since the doctrine of descent of animals and plants began to be accepted, naturalists have had a better criterion for determining relationships. Animals exhibit relationships because they have sprung from a common stock. The members of a natural group resemble one another in structure because they have a genetic relationship and the closer the resemblances the closer the kinship. Even on this basis, there is no agreement among zoölogists as to the number of phyla into which the animal kingdom should be divided. Some find the need to recognize only eight while others maintain that there should be as many as twenty or even more. Except as it bears on the work of von Siebold and Leuckart this is a matter of small importance in our story. Doubtless the division of some of the primary groups is justified on technical grounds, but as Richard Hertwig has remarked: "In this way groups poor in species and of little importance in a general account of the animal kingdom are placed on the same basis as the large and exceedingly important groups of vertebrates, arthropods and molluscs and thus obtain, especially in the eyes of the beginner, an importance that does not belong to them."

Louis Agassiz in his famous essay on Classification reviews in a scholarly way the various systems of Classification proposed up to 1859. One feature of Agassiz's philosophy was his adherence to the dogma of the constancy of species. The same year in which his essay appeared there was published Darwin's *Origin of Species* and this lighted the way to the systematic arrangement of animals and plants on the basis of genetic relationship. This is not the place to enter upon a special consideration of the influence of the *Origin of Species* upon all biology but the steps in biological progress from Linnæus to Darwin may be summarily stated.

STEPS IN BIOLOGICAL PROGRESS FROM LINNÆUS TO DARWIN

The period from Linnæus to Darwin is one full of important advances for biology in general. We have considered in this chapter only those features that related to changes in the system of classification, but in the meantime the morphological and the physiological sides of biology were being advanced not only by an accumulation of facts, but by their better analysis. It is an interesting fact that, although during this period the details of the subject were greatly multiplied, progress was relatively straightforward and by a series of steps that can be clearly indicated.

It will be of advantage before the subject is taken up in its parts to give a brief forecast in which the steps of progress can be represented in outline without the confusion arising from the consideration of details. Geddes, in 1898, pointed out the steps in progress, and the account that follows is based upon his lucid analysis.

The Organism. In the time of Linnæus the attention of naturalists was mainly given to the organism as a whole. Plants and animals were considered from the standpoint of the organism — the external features were largely dealt with, the habitat, the color, and the general appearance — features which characterize the organism as a whole. Linnæus and Jussieu represent this phase of the work, and Buffon the higher type of it. Modern studies in this line are like additions to the *Systema naturæ.*

Organs. The first distinct advance came in investigating animals and plants according to their structure. Instead of the complete organism, the organs of which it is composed became the chief subject of analysis. The organism was dissected, the organs were examined broadly, and those of one kind of animal and plant compared with another. This kind of comparative study centered in Cuvier, who, in the early part of the nineteenth century, founded the science of comparative anatomy of animals, and in Hofmeister, who examined the structure of plants on a basis of broad comparison.

Tissues. Bichat, the famous contemporary of Cuvier, essayed

a deeper level of analysis in directing attention to the tissues that are combined to make up the organs. He distinguished twenty-one kinds of tissues by combinations of which the organs are composed. This step laid the foundation for the science of histology, or minute anatomy. Bichat called it general anatomy (Anatomie Générale, 1801).

Cells. Before long it was shown that tissues are not the real units of structure, but that they are composed of microscopic elements called cells. This level of analysis was not reached until magnifying-lenses were greatly improved — it was a product of a closer scrutiny of nature with improved instruments. The foundation of the work, especially for plants, had been laid by Leeuwenhoek, Malpighi, and Grew. But when the broad generalization, that all the tissues of animals and plants are composed of cells, was given to the world by Schleiden and Schwann, in 1838–1839, the entire organization of living forms took on a new aspect. This was progress in understanding the morphology of animals and plants.

Protoplasm. With improved microscopes and attention directed to cells, it was not long before the discovery was made that the cells as units of structure contain protoplasm and that, in fact, a " cell " is a small mass of protoplasm usually containing a nucleus. That this substance is similar in plants and animals and is the seat of all vital activity was determined chiefly by the researches of Max Schultze, published in 1861. Thus step by step, from 1758, the date of the tenth edition of the *Systema naturæ,* to 1861, there was a progress on the morphological side, passing from the organism as a whole to organs, to tissues, to cells, and finally to protoplasm, the study of which in all its phases is the chief pursuit of biologists.

The physiological side had a parallel development. In the period of Linnæus, the physiology of the organism was investigated by Haller and his school; following him the physiology of organs and tissues was advanced by J. Müller, Bichat, and others. Later, Virchow investigated the physiology of cells, and Claude Bernard the chemical activities of protoplasm.

CHAPTER XVI

CUVIER AND THE COMPARATIVE ANATOMY OF ANIMALS

After Linnæus and his followers had developed a whole "system of nature" based on the study of externals, it was natural that a reaction should set in. The more discerning naturalists saw that the study of externals was inadequate even for the purposes of classification, and that there could be little advance of knowledge regarding the true nature of living beings without a knowledge of internal structure and the purpose of structure. Naturalists of this type devoted their attention to dissection and anatomical analysis on an extensive scale; when their investigations became broadly comparative, a new science of comparative anatomy arose. In due course of time this was the basis for the development of comparative physiology, but for the present we follow only the rise of the comparative anatomy of animals. The materials out of which the science of comparative anatomy was constructed had been long accumulating before the advent of Cuvier, but the mass of details had not been organized into a compact science.

As indicated in previous chapters, there had been an increasing number of studies upon the structure of organisms, both plant and animal, and there had resulted some noteworthy monographs. All this work, however, was mainly descriptive, and not comparative. Now and then the comparing tendency had been shown in isolated writings such as those of Belon, Harvey, Malpighi, and others. As early as 1555, Belon had compared the skeleton of the bird with that of the human body "in the same posture and as nearly as possible bone for

bone " ; but this was merely a faint foreshadowing of what was to be done later on a broad and comprehensive scale.

We should keep in mind that the study of anatomy embraces not merely the bony framework of animals, but also the muscles, all the internal organs, the nervous system, the sense organs, etc., and that it applies to plants as well as to animals. In the rise of comparative anatomy there gradually emerged naturalists who compared the structure of the higher animals with that of the simpler ones. These comparisons brought out so many resemblances and so many remarkable facts that anatomy changed from the state of a descriptive science which is dry and formal, to comparative anatomy, a subject rich in ideas and of very great interest even to the layman.

SEVERINUS

The first book expressly devoted to comparative anatomy was that of Severinus (1580–1656), designated *Zoötomia Democritæ*. The title preserves the name of the Roman naturalist Democritæus, and the date of its publication, 1645, places the treatise earlier than the works of Malpighi, Leeuwenhoek, and Swammerdam. The book is illustrated by numerous coarse woodcuts, showing the internal organs of fishes, birds, and some mammals. There are also a few illustrations of stages in the development of these animals. The comparisons were superficial and incidental; nevertheless, as the first attempt, after the revival of anatomy, to make the subject comparative, it has some especial interest.

FORERUNNERS OF CUVIER

Anatomical studies began to take on broader features with the work of Camper, John Hunter, and Vicq-d'Azyr. These three men paved the way for Cuvier, but it must be said of Camper that his comparisons were limited and unsystematic.

Camper (Fig. 100), was born in Leyden, in 1722. He was a versatile man, having a taste for drawing, painting, and sculpture, as well as for scientific studies. He received his scientific training

under Boerhaave and other eminent men in Leyden, and became a professor and, later, rector in the University of Groningen. Possessing an ample fortune, he was in position to follow his own tastes. He traveled extensively and gathered a large collec-

FIG. 100. — PIETER CAMPER, 1722–1789.

tion of skeletons. He showed considerable talent as an anatomist, and he made several discoveries, which, however, he did not develop, but left to others. Perhaps the possession of riches was one of his limitations; at any rate, he lacked fixity of purpose.

Among his discoveries may be mentioned the semicircular canals of the ear in fishes, the fact that the bones of flying birds are permeated by air, and the determination of some fossil bones, with the suggestion that they belonged to extinct forms. The latter point is of interest, as antedating the conclusions of

Cuvier regarding the nature of fossil bones. Camper also made observations upon the facial angle as an index of intelligence in the different races of mankind, and in lower animals. He studied the anatomy of the elephant, the whale, the orang, etc.

John Hunter (1728–1793), the gifted Scotchman whose museum in London has been so justly celebrated, was a man of extraordinary originality, who read few books but went directly to nature for his facts; and, although he made errors from which he would have been saved by a wider acquaintance with

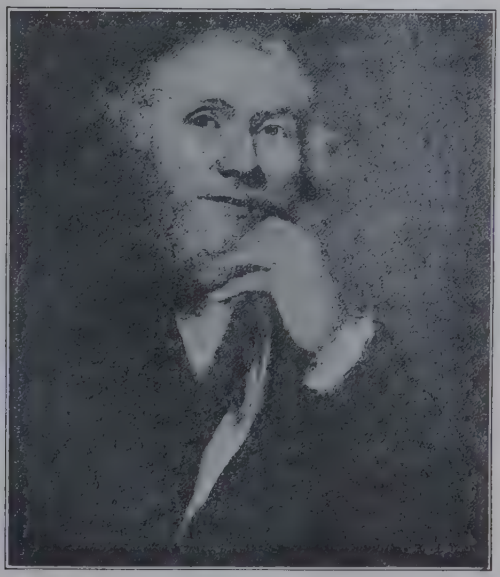

Fig. 101. — John Hunter, 1728–1793.

the writings of naturalists, his neglect of reading left his mind unprejudiced by the views of others. His great originality and intuitive insight secured for him an exalted place in surgery, and the same qualities made him one of the foremost pioneers in comparative anatomy. Garrison says that he was "with Paré and Lister one of the three greatest surgeons of all time." His

fame grew after his death; he was venerated by his students — Jenner, of vaccination fame, Sir Astley Cooper, Abernethy, and other celebrated surgeons who owed to him their training in methods and principles. In the middle of the nineteenth century his remains were removed from the place of their first burial and interred in Westminster Abbey among the most famous of Britain's personalities. The Hunterian oration delivered in his memory has become an annual event in the medical world. It is not, however, his fame as a surgeon that brings his name into this chapter but his work in comparative anatomy and natural history. We shall see later that his work in comparative anatomy was so interrupted by his professional engagements and spread over such a wide range that, although he assembled the materials, performed the preliminary dissections, and made single contributions, they were not organized into a whole. He was a great pioneer explorer, but he cannot in truth be considered as the founder of comparative anatomy.

At the age of twenty, John Hunter came to London to study anatomy under his brother William who was already established in practice. John was "a raw, uncouth Scotch lad, fonder of taverns and theater galleries than of book-learning." He was a wild, unruly spirit who would not be forced into conventional mold as regards either education or manners. Nevertheless, he showed remarkable patience and thoroughness in working out the more intricate structures of the human body, and in the second winter he was placed in charge of the practical work of his brother's classes. Soon thereafter he attended lectures at Chelsea Military Hospital. He became a surgeon's pupil under Pott at St. Bartholomew's and fitted himself for the practice of surgery. John was crude and abrupt. His brother William on the contrary was a man of elegant manners and refined speech, who well understood the value of polish in reference to worldly success, and before allowing John to struggle for surgical practice, he made one more effort for his improvement. He arranged for him to go to Oxford, but after a month's residence there, the Philistine spirit of John rebelled; he would not

have the classical education of the University nor would he take on the refinements of taste and manner of which his brother was a good example. All his life he showed the lack of early education; he was an awkward lecturer, with poverty of language for expressing his ideas, but he succeeded through his innate genius and capacity for prolonged and concentrated effort. He had a passion for investigation; by aptitude and personal inclination he was a naturalist. Had not his support depended on his practice, which absorbed much of his time and energies, doubtless he would have come to occupy a position of greater eminence in natural history. As it was, his prodigious application, his remarkable fertility and suggestiveness made him one of the most conspicuous forerunners of Cuvier. His dissections were more comprehensive than those of Vicq-d'Azyr, but his comparisons were not so specific and methodical.

He spent lavishly of his income in getting animals from all quarters of the globe. His country-place at that time outside London was a veritable menagerie; there he studied all sorts of native animals such as bees, fish, frogs, ducks, geese, pigeons, hedgehogs, cattle, sheep, etc., and kept under observation a number of exotic forms such as the lion, leopard, buffalo, a shawl-goat from Persia, etc. "Animals dying at the Tower of London and the city menageries were obtained by Hunter for dissection and no unusual animal was brought to England during the latter part of his career without his having an opportunity to examine it." He injected the blood vessels and anatomized numerous invertebrates as well as vertebrates. When necessary these preparations were preserved in "spirits" and together with skeletons and other dry specimens constituted his great museum.

The original collections made by Hunter are still open to inspection in the rooms of the Royal College of Surgeons, London. It was his object to preserve specimens to illustrate the phenomena of life in all organisms, whether in health or disease, and the extent of his museum may be imagined from the circumstance that he expended upon it about three hundred and seventy-five thousand dollars. Although he described and com-

pared many types of animals, it was as much in bringing this collection together and leaving it to posterity that he advanced comparative anatomy as in what he wrote. His preparations were carefully inspected by Cuvier and Mackel and extensively used by Richard Owen. After his death the House of Commons purchased his museum for fifteen thousand pounds, and placed it under the care of the Corporation of Surgeons.[2]

From comparative studies he arrived at the idea of a graded series of animals and suggested a phylogenetic classification. He compared the anatomical structure of apes, monkeys, and lemurs with that of man and thereby foreshadowed Huxley's great essay on *Man's Place in Nature* (1861). He broke ground in the study of the fossil series. He was vastly suggestive; Darwin pays tribute to Hunter both in the *Origin of Species* and in his *Descent of Man.* Libby[3] has pointed out that the last two-thirds of the *Descent of Man* is based on principles laid down by Hunter.

It has been variously suggested that he owed his inspiration or at least his method of work to Francis Bacon, but G. G. Babington in one of the Hunterian orations says: "He had never read Bacon, but his method of studying nature was as strictly Baconian as if he had." John Hunter was a genius *sui generis.*

Vicq-d'Azyr (Fig. 102), more than any other man, holds the chief rank as a comparative anatomist before the advent of Cuvier into the same field. He was born in 1748, the son of a physician, and went to Paris at the age of seventeen to study medicine, remaining in the metropolis to the time of his death in 1794. He was celebrated as a physician, became permanent secretary of the newly founded Academy of Medicine, consulting physician to the queen, and occupied other positions of trust and responsibility. He married the niece of Daubenton, and, largely through his influence, was advanced to social place and recognition. On the death of Buffon, in 1788, he took the seat of that distinguished naturalist as a member of the French Academy.

[2] The museum of his brother William was bequeathed to the University of Glasgow and is also known as the "Hunterian Museum."

[3] *The History of Medicine in Its Salient Features,* 1922, p. 171.

He made extensive studies upon the organization particularly of birds and quadrupeds, making comparisons between their structure, and bringing out new points that were superior to anything yet published. His comparisons of the limbs of man and animals, showing a correspondence between the flexor and

FIG. 102. — FÉLIX VICQ-D'AZYR, 1748–1794. (Enlarged from a small medallion on the cover of the *Encyclopédie Methodique*.)

extensor muscles of the legs and arms, were made with great exactness, and they served to mark the beginning of a new kind of precise comparison. These were not mere superficial comparisons, but exact ones — part for part; and his general considerations based upon these comparisons were of a brilliant character.

As Huxley has said, "he may be considered as the founder of the modern science of anatomy." His work on the structure of the brain was the most exact which had appeared up to that time, and in his studies on the brain he entered into broad comparisons as he had done in the study of the other parts of the animal organization.

He died at the age of forty-six, without being able to complete a large work on human anatomy, illustrated with colored

figures. This work had been announced and entered upon, but only that part relating to the brain had appeared at the time of his death. Besides drawings of the exterior of the brain, he made sections; but he was not able to determine with any particular degree of accuracy the course of fiber tracks in the brain. This was left for later workers. He added many new facts to those of his predecessors, and by introducting exact comparisons in anatomy he opened the field for Cuvier.

CUVIER

When Cuvier, near the close of the eighteenth century, committed himself definitely to the progress of natural science, he found vast accumulations of separate monographs to build upon, but he undertook to dissect representatives of all the groups of animals, and to found his comparative anatomy on personal observations. The work of Vicq-d'Azyr marked the highest level of attainment, and afforded a good model of what comparisons should be; but Cuvier had even larger ideas in reference to the scope of comparative anatomy than had his great predecessor.

The particular feature of Cuvier's service was that in his investigations he covered the whole field of animal organization from the lowest to the highest, and uniting his results with what had already been accomplished, he established comparative anatomy on broad lines as an independent branch of natural science. Almost at the outset he conceived the idea of making a comprehensive study of the structure of the animal kingdom. It was fortunate that he began his investigations with thorough work upon the invertebrated animals; for from this point of view there was gradually unfolded to his mind the plan of organization of the entire series of animals. Not only is a knowledge of the structure of the simplest animals an essential factor in understanding that of the more modified ones, but the more delicate work required in dissecting them gives invaluable training for anatomizing those of more complex construction. The value attached to this part of his training by Cuvier is illustrated by the advice that he gave to a young medical student who

brought to his attention a supposed discovery in anatomy. "Are you an entomologist?" inquired Cuvier. "No," said the young man. "Then," replied Cuvier, "go first and anatomize an insect, and return to me; and if you still believe that your observations are discoveries I will then believe you."

Birth and Early Education. Cuvier was born in 1769, at Montbéliard, a village at that time belonging to Württemberg, but now a part of the French Jura. His father was a retired military officer of the Swiss army, and the family, being Protestants, had moved to Montbéliard for freedom from religious persecution. Cuvier was christened Léopold-Christian-Frédéric-Dagobert Cuvier, but early in youth took the name of Georges at the wish of his mother, who had lost an infant son of that name.

He gave early promise of intellectual leadership, and his mother, although not well educated, took the greatest pains in seeing that he formed habits of industry and continuous work, hearing him recite his lessons in Latin and other branches, although she did not possess a knowledge of Latin. He early showed a leaning toward natural history; having access to the works of Gesner and Buffon, he profited by reading these two writers. So great was his interest that he colored the plates in Buffon's *Natural History* from descriptions in the text.

It was at first contemplated by his family that he should prepare for theology, but failing, through the unfairness of one of his teachers, to get an appointment to the theological seminary, his education was continued in other directions. He was befriended by the sister of the Duke of Württemberg, who sent him as a pensioner to the famous Carolinian academy at Stuttgart. There he showed great application, and with the wonderful memory with which he was endowed, he took high rank as a student. Here he met Kielmeyer, a young instructor only four years older than himself, who shared his taste for natural history and, besides this, introduced him to anatomy. In after-years Cuvier acknowledged the assistance of Kielmeyer in determining his future work and in teaching him to dissect.

Life at the Seashore. In 1788 the resources of his family, which had always been slender, became further reduced by the inability of the government to pay his father's retiring stipend. As the way did not open for employment in other directions, young Cuvier took the post of instructor of the only son in the family of Count d'Héricy, and went with the family to the seacoast in Normandy, near Caen. For six years (1788–1794) he lived with this noble family, and much of this time was at his own disposal. For Cuvier this period, from the age of nineteen to twenty-five, was one of constant research and reflection.

While Paris was disrupted by the reign of terror, Cuvier, who, although of French descent, regarded himself as a German, was quietly carrying on his researches into the structure of the life at the seaside. These years of diligent study and freedom from distractions fixed his destiny. Here at the seacoast, without the assistance of books and the stimulus of intercourse with other naturalists, he was drawn directly to nature, and through his great industry he became an independent observer. Here he laid the foundation of his extensive knowledge of comparative anatomy, and from this quiet spot he sent forth his earliest scientific writings, which served to carry his name to Paris, the great center of scientific research in France.

Goes to Paris. His removal from these provincial surroundings was mainly owing to the warm support of Tessier, who was spending the time of the reign of terror in retirement in an adjacent village, under an assumed name. He and Cuvier met in a scientific society, where the identity of Tessier was discovered by Cuvier on account of his ease of speech and his great familiarity with the topics discussed. A friendship sprang up between them, and Tessier addressed some of his scientific friends in Paris in the interest of Cuvier. By this powerful introduction, and also through the intervention of Geoffroy Saint-Hilaire, he came to Paris in 1795 and was welcomed into the group of working naturalists at the Jardin des Plantes, little dreaming at the time that he should become the leader of the group of men gathered around this scientific institution. He was modest, and

so uncertain of his future that for a year he held to his post of instructor, bringing his young charge with him to Paris.

Notwithstanding the doubt which he entertained regarding his abilities, his career proved successful from the beginning. In Paris he entered upon a brilliant career, which was a succession of triumphs. His unmistakable talent, combined with industry and unusual opportunities, brought him rapidly to the front. The large amount of material already collected, and the stimulating companionship of other scientific workers, afforded an environment in which he grew rapidly. He responded to the stimulus, and developed not only into a great naturalist, but expanded into a finished gentleman of the world. Circumstances shaped themselves so that he was called to occupy prominent offices under the government, and he came ultimately to be the head of the group of scientific men into which he had been welcomed as a young man from the provinces.

His Physiognomy. It is very interesting to note in his portraits the change in his physiognomy accompanying his transformation from a young man of provincial appearance into an elegant personage. Fig. 103 shows his portrait in the early days when he was less mindful of his personal appearance. It is the face of an eager, strong, young man, still retaining traces of his provincial life. His long, light-colored hair is unkempt, but does not hide the magnificent proportions of his head. Fig. 104 shows the growing refinement of features which came with his advancement, and the aristocratic look of supremacy which set upon his countenance after his wide recognition passing by a gradation of steps from the position of head of the educational system to that of baron and peer of France.

Cuvier was a man of commanding power and colossal attainments; he was a favorite of Napoleon Bonaparte, who elevated him to office and made him director of the higher educational institutions of the Empire. But to whatever place of prominence he attained in the government, he never lost his love for natural science. With him this was an absorbing passion, and it may be said that he ranks higher as a zoölogist than as a statesman.

Comprehensiveness of Mind. Soon after his arrival in Paris, he began to lecture upon comparative anatomy and to continue work in a most comprehensive way upon the subjects which he

Fig. 103. — Georges Cuvier (1769–1832), As A Young Man.

had cultivated at Caen. He saw everything on a large scale. This led to his making extensive studies of whatever problems engaged his mind, and his studies were combined in such a manner as to give a broad view of the subject.

Indeed, comprehensiveness of mind seems to have been the characteristic which most impressed those who were acquainted with him. Flourens says of him: "Ce qui caractérise partout M. Cuvier, c'est l'esprit vaste." His broad and comprehensive mind enabled him to map out on great lines the subject of comparative anatomy. His breadth was at times his undoing, for it must be confessed that when the details of the subject are considered, he was often inaccurate. This was possibly owing to the conditions under which he worked; having his mind diverted into many other channels, never neglecting his state

duties, it is reasonable to suppose that he lacked the necessary time to prove his observations in anatomy, and we may in this way account for some of his inaccuracies.

Besides being at fault in some of his comparative anatomy, he adhered to a number of personal views that served to retard the progress of science. He was opposed to the ideas of his con-

FIG. 104. — CUVIER AT THE ZENITH OF HIS POWER.

temporary Lamarck, on the evolution of animals. He is remembered as the author of the dogma of catastrophism in geology. He adhered to the old notion of the pre-formation of the embryo, and also to the theory of the spontaneous origin of life.

Founds Comparative Anatomy. Regardless of this qualifica-

tion, he was a great and distinguished student, and founded comparative anatomy. From 1801 to 1805 appeared his *Le ons d'Anatomie Comparée,* a systematic treatise on the comparative anatomy of animals, embracing both the invertebrates and the vertebrates. In 1812 was published his great work on the fossil bones about Paris, an achievement which founded the science of vertebrate palæontology. His extensive examination of the structure of fishes also added to his already great reputation. His book on the animal kingdom (*Le Règne Animal distribué d'après son Organisation,* 1816), in which he expounded his type-theory, has been considered in a previous chapter.

He was also deeply interested in the historical development of science, and his volumes on the rise of the natural sciences give us almost the best historical estimate of the progress of science that we have at the present day.

His Domestic Life. Mrs. Lee, in a chatty account of Cuvier, shows one of his methods of work. He had the faculty of making others assist him in various ways. Not only members of his family, but also guests in his household were pressed into service. They were invited to examine different editions of works and to indicate the differences in the plates and in the text. This practice resulted in saving much time for Cuvier, since in the preparation of his historical lectures he undertook to examine all the original sources of the history with which he was engaged. In his lectures he summarized facts relating to different editions of books, etc.

Mrs. Lee also gives a picture of his family life, which was, to all accounts, very beautiful. He was devoted to his wife and children, and in the midst of exacting cares he found time to bind his family in love and devotion. Cuvier was called upon to suffer poignant grief in the loss of his children, and his direct family was not continued. He was especially broken by the death of his daughter who had grown to young womanhood and was about to be married.

From the standpoint of a sincere admirer, Mrs. Lee writes of his generosity and nobility of temperament, declaring that his

career demonstrated that his mind was great and free from both envy and smallness.

Some Shortcomings. Nevertheless, there are certain things in the life of Cuvier that we wish might not have been. His break with his old friends, Lamarck and Saint-Hilaire, seems to show a domination of qualities that were not generous and kindly; those observations of Lamarck showing a much profounder insight than any of which he himself was the author were laughed to scorn. His famous controversy with Saint-Hilaire marks a historical moment that will be dealt with in the chapter on Rise of Evolutionary Thought.

George Bancroft, the American historian, met Cuvier during a visit to Paris in 1827. He speaks of his magnificent eyes and his fine appearance, but on the whole Cuvier seems to have impressed Bancroft as a disagreeable man.

Some of his shortcomings that served to retard the progress of science have been mentioned. Still, with all his faults, he dominated zoölogical science at the beginning of the nineteenth century, and so powerful was his influence and so undisputed was his authority among the French people that the rising young men in natural science sided with Cuvier even when he was wrong. It is a noteworthy fact that France, under the influence of the traditions of Cuvier, was the last country slowly and reluctantly to harbor as true the ideas regarding the evolution of animal life.

CUVIER'S SUCCESSORS

While Cuvier's theoretical conclusions exercised a retarding influence upon the progress of biology, his practical studies more than compensated for this. It has been pointed out how his type-theory led to the reform of the Linnæan system, but, besides this, the stimulus which his investigations gave to studies in comparative anatomy was even of more beneficent influence. As time passed the importance of comparative anatomy as one division of biological science impressed itself more and more upon naturalists. A large number of investigators in France,

England, and Germany entered the field and took up the work where Cuvier had left it.

The more notable of his intellectual heirs in France were Milne-Edwards and Lacaze-Duthiers.

MILNE-EDWARDS

H. Milne-Edwards (1800–1885) was a man of great industry and fine attainments; prominent alike in comparative anatomy, comparative physiology, and general zoölogy, professor for many years at the Sorbonne in Paris. In 1827 he introduced into

Fig. 105. — Henri Milne-Edwards, 1800–1885.

biology the fruitful idea of the division of physiological labor. He completed and published excellent researches upon the structure and development of many animals, notably crustacea, corals, etc. His work on comparative anatomy took the form of explanations of the activities of animals, or comparative physiology. His comprehensive treatise *Leçons sur la Physiologie et l'Anatomie Comparée,* in fourteen volumes, 1857–1881, is a mine of information regarding comparative anatomy as well as the physiology of organisms.

LACAZE-DUTHIERS

Henri de Lacaze-Duthiers, one of the most brilliant of French naturalists, was a disciple of H. Milne-Edwards. He stands as an early representative of experimental zoölogy and he did much to

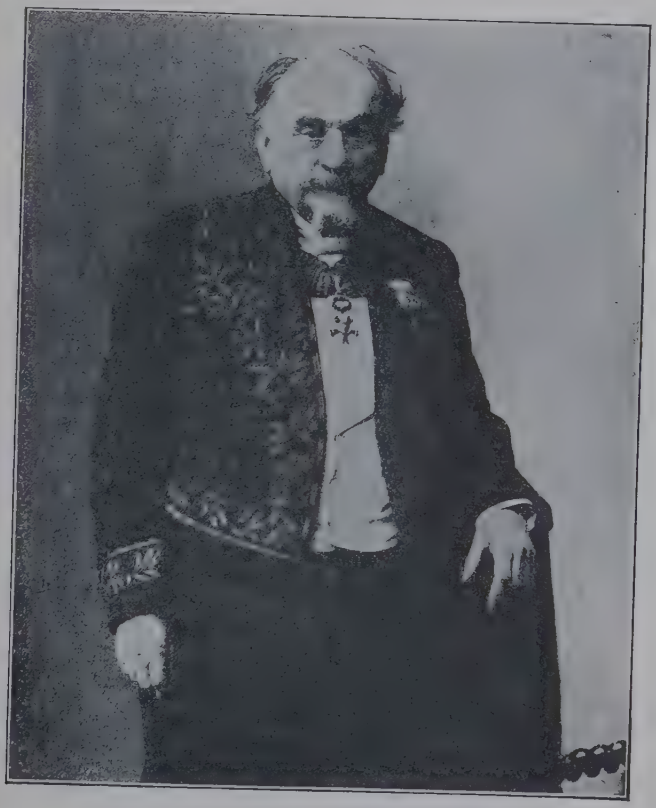

FIG. 106. — HENRI DE LACAZE-DUTHIERS, 1821–1901.

carry forward comparative anatomy on new lines. Born in 1821, the son of a patrician family living in the Dordogne region, at the age of seventeen he was graduated from the College of Toulouse with a grade in physical sciences. He showed a bent towards

natural history and had made some observations on insects and other animals, but his father, the baron, an austere man who ruled his family with an iron hand, opposed his devotion to natural history which he regarded as a trivial pursuit and undignified as a career. As a sort of compromise Henri went to Paris to study medicine. At the Sorbonne he was inspired by the teaching of H. Milne-Edwards and de Blainville and pursued natural history subjects with singular devotion. At the age of twenty-four having received the grade of *licencié-ès-sciences,* he became an assistant to Milne-Edwards at the Sorbonne and at the same time continued his study of medicine. He attained the degree of Doctor of Medicine in 1851 and that of Doctor of Science in 1853. After some travels in Spain and France and a temporary position in the agricultural station at Versailles, he went to Lille as professor of botany and zoölogy while Pasteur was still dean of the faculty of sciences. After nine years at Lille he went to Paris where he held successively positions at l'École Normale Supérieure, at the museum of natural history, and finally in 1869, he replaced Gratiolet as professor of comparative anatomy, zoölogy and physiology at the Sorbonne. He held professorships for forty-seven years — thirty-two of which were at the Sorbonne and he profoundly influenced the growth of comparative anatomy and zoölogy in France.

Up to 1870 his life had been one of intense personal productivity, then came the dark days of the war with Germany by which he was depressed and saddened, but, like Pasteur under the same circumstances, he determined to work for the glory of his country with renewed energy. Although, after 1870, he continued to publish researches, his great work was in communicating to others his love of science and in making their work easier. He was able in 1872 to accomplish a long-cherished wish of founding a research station at the seaside for the study of experimental zoölogy. From 1872 to 1880 he was much occupied with his marine biological station at Roscoff — devising new methods, new technique and directing the work of students. At the same time (1872) he founded the Archives of Experi-

mental Zoölogy [4] as a periodical for the publication of researches in the new field.

Lacaze-Duthiers opened the field of experimental morphology which in later years developed into an important line of research and has contributed so much to the advancement of anatomy and embryology. It is of some historical interest to note his position of extreme caution on the question of organic evolution — a subject which was attracting lively attention in his day. He did not believe in the fixity of species but regarded the question of their descent as a philosophical one not capable of scientific demonstration. He says, "I am not antagonistic to Darwin but troubled by difficulties of explanation." Thus relatively early he began to distinguish between the fact of evolution and the factors. Essentially he was an evolutionist but not satisfied with natural selection as its agency. He also founded the marine station at Banyuls-sur-mer and established there a delightful residence and quiet retreat from the turmoil of Paris. He died in 1902 and is buried at Banyuls. His scientific bibliography numbers some two hundred fifty-six titles.

R. OWEN

In England Richard Owen (1804–1892) carried on the influence of Cuvier. At the age of twenty-seven he went to Paris and renewed acquaintance with Cuvier, whom he had met the previous year in England. He spent some time at the Jardin des Plantes examining the extensive collections in the museum. It has been claimed that the collections of fossil animals and the researches upon them which engaged Cuvier at that time had great influence upon the subsequent studies of Owen. This suggestion, however, was not agreeable to Owen and he disclaimed any debt to the French anatomist. He never studied under Cuvier, still in a sense he may be regarded as his disciple. All his life he had close at hand the preparations of John Hunter which were of assistance in the preparation of his scientific papers, lectures, and his books. Owen introduced into comparative anatomy the

[4] *Archives de Zoölogie expérimentale et générale*, 1872.

important conceptions of analogy and homology, the former being a likeness based upon the use to which organs are put, as the wing of a butterfly, and the wing of a bat; while homology is a true relationship founded on likeness in structure and development, as the wing of a bat and the foreleg of a dog. Analogy is a superficial, and often a deceiving relationship; homology is a true genetic relationship. It is obvious that this distinction is of great importance in comparing the different parts of animals. He made a large number of independent discoveries, and published a monumental work on the comparative anatomy of vertebrates (1866–1868). In much of his thought he was singular, and many of his general conclusions have not stood the test of time. He undertook to establish the idea of an archtype in vertebrate anatomy. He clung to the vertebrate theory of the skull long after Huxley had shown such a theory to be untenable. The idea that the skull is made up of modified vertebræ was propounded by Goethe and Oken. In the hands of Oken it became one of the anatomical conclusions of the school of *Naturphilosophie*. This school of transcendental philosophy mixed in nearly all scientific questions of the day; its votaries paid little heed to verification of observations and became so unrestrained in speculation that a reaction set in against it which resulted in its downfall. The vertebral theory of the skull was not original with Owen, but he adopted it, greatly elaborated it, and clung to it blindly long after the foundations upon which it rested were removed.

In England Richard Owen (Fig. 107) was succeeded by Huxley (1825–1895), whose exactness of observation and rare judgment as to the main facts of comparative anatomy mark him as one of the leaders in this field of research. The influence of Huxley as a popular exponent of science is dealt with in a later chapter.

MECKEL

Just as Cuvier stands at the beginning of the school of comparative anatomy in France, so does J. Fr. Meckel in Germany.

Meckel (1781–1833) was a man of rare talent, descended from a family of distinguished anatomists. From 1804 to 1806, he studied in Paris under Cuvier, and when he left the French capital to become professor of anatomy at Halle, he carried

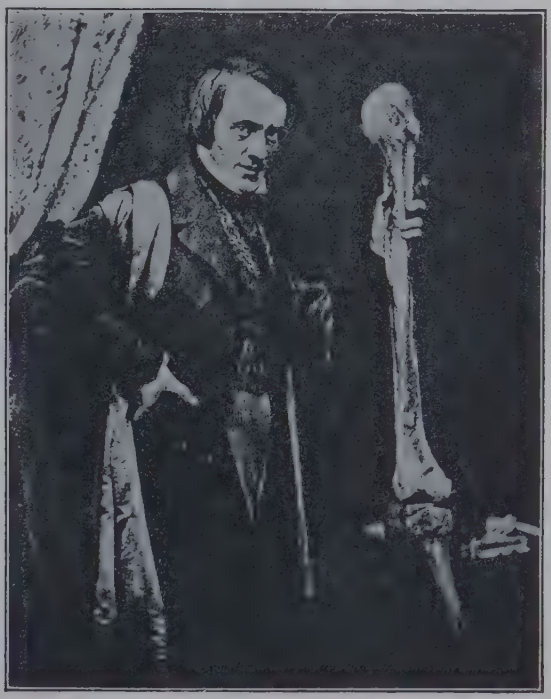

Fig. 107. — Richard Owen, 1804–1892.

into Germany the teachings and methods of his master. He was a strong force in the university, attracting students to his department by his excellent lectures and his ability to arouse enthusiasm. Some of these students were stimulated to undertake researches in anatomy, and there came from his laboratory a number of investigations that were published in a periodical which he founded. Meckel himself produced many scientific

papers and works on comparative anatomy, which assisted materially in the advancement of that science. Comparative anatomy, as well as its adjunct, embryology, took a strong hold in Germany so that researches in these two lines become almost a feature of German biological science. Two or three of Meckel's successors should be mentioned.

Fig. 108. — J. Fr. Meckel, 1781–1833.

RATHKE

Martin Henry Rathke (1793–1860) greatly advanced the science of comparative anatomy by insisting upon the importance of elucidating anatomy with researches in development. This is such an important consideration that his influence upon the progress of comparative anatomy cannot be overlooked. After being a professor in Dorpat, he came, in 1835, to occupy the professorship of anatomy and zoölogy at Königsberg, which position had been vacated by Von Baer on the removal of the latter to St. Petersburg. Rathke's writings are composed with great intelligence, and his facts are carefully coördinated. Rathke belonged to the good old school of German writers whose researches were profound and extensive, and whose expression was clear, being based upon matured thought. His papers on the aortic arches and the Wolffian body are those most commonly referred to at the present time.

MÜLLER

Johannes Müller (1801–1858), the physiologist, also gave attention to comparative anatomy, and earned the title of the greatest morphologist of his time. His researches were so accu-

rate, so complete, so discerning, that his influence upon the development of comparative anatomy was profound. Although he had the double distinction of being a great anatomist and a great physiologist, his teaching tended to physiology; and most of his distinguished students were physiologists of the broadest type, uniting comparative anatomy with their researches upon functional activities.

GEGENBAUR

In Karl Gegenbaur (1826–1903) scientific anatomy reached its highest expression. His work was characterized by broad and masterly analysis of the facts of structure, to which were

Fig. 109. — Karl Gegenbaur, 1826–1903.

added the ideas derived from the study of the development of organs. He was endowed with an intensely keen insight, an insight which enabled him to separate from the vast mass of facts the important and essential features, so that they yielded results of great interest and of lasting importance. Gegenbaur candidly

applied the theory of phylogenetic descent to the problems of comparative anatomy and gave to the science a meaning and a significance that it had never had before. This gifted anatomist attracted many young men from the United States and from other countries to pursue under his direction the study of comparative anatomy. He died in Heidelberg in 1903, where he had been for many years professor of anatomy in the university.

To speak in particular of the researches of the more recent German anatomists such as Fürbringer, Waldeyer, and Wiedersheim would carry us beyond the prescribed limits of this book.

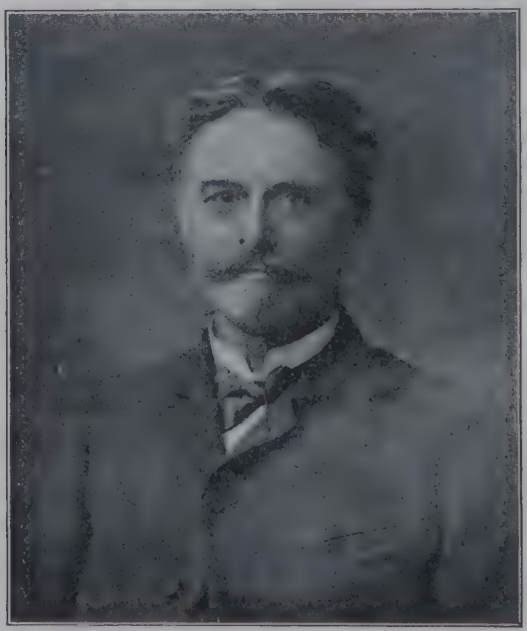

Fig. 110. — E. D. Cope, 1840–1897.

E. D. COPE

In the United States the greatest comparative anatomist was E. D. Cope (1840–1897), a man of the highest order of attainment, who dealt with the comparative anatomy not only of living

but also of fossil animals and made contributions of a permanent character to this great science. It is not invidious to say that in all probability, as the worth of his work is fully appreciated, he will come to be estimated as the equal of Cuvier in comparative anatomy.

When pursued by modern methods and in close union with embryology, comparative anatomy is a fertile field for cultivation. The contrast between pure descriptive anatomy and comparative anatomy is striking. The former is relatively barren, yielding a mass of individual facts; the harvest from the latter is rich and abundant; it gives rise to ideas and interpretations that are of great interest to the layman as well as to the specialist. Training in comparative anatomy remains today as the best foundation for the more recently developed lines of zoölogical investigations such as genetic cytology and general physiology. In the last fifty years it has become experimental and the outlook for further advances in experimental morphology is most promising.

CHAPTER XVII

PROGRESS OF BOTANY FROM LINNÆUS TO SCHLEIDEN

In Chapter Eight on the Makers of Herbals we followed in outline the botanical advances to the time of Cesalpino (1583) and Caspar Bauhin (1623); we now take up the story of the fortunes of botany from Linnæus (about 1750) to Schleiden (about 1840). A brief retrospective glance at the progress of botany from Cesalpino to Linnæus is essential at this point to remind us of the condition of the science when Linnæus took it in hand as well as to show the sources from which he drew much of his material.

Going back to the revival of botany in the first half of the sixteenth century, we find Bock and, especially, Valerius Cordus giving the first vivid word pictures of plants. After Bock and Cordus a great number of descriptions of individual plants had accumulated and certain broad principles of classification had been formulated. Obviously, the latter are of more importance. The description of new species enlarged the mass of botanical knowledge without doing anything to clarify it. There was needed some system of orderly arrangement of plants combining them into groups on the basis of natural relationships, and the men who worked toward that end were more advanced in their views than describers of individual plants. They perceived one of the fundamental requirements for the progress of botany.

SOME PRE-LINNÆAN BOTANISTS

The pre-Linnæan workers toward a natural classification of plants are represented by Cesalpino, Caspar Bauhin, Jung, John Ray, and a few others as Bachmann and Tournefort.

Cesalpino, in his publication of 1583 (cf. p. 135) sought for some principle upon which to base a natural classification of

plants. By philosophical reflection he attempted to determine the recognition-marks of relationship among plants; but since the discovery of natural affinities must be based on objective study his method was inadequate.

Caspar Bauhin, after forty years of work and with a knowledge of plants unsurpassed in his time, made another attempt. This is best shown in his famous "Pinax" of 1623. As previously stated, Bauhin used likeness of habits in his effort to determine natural relationships, but lack of knowledge of embryology and the common ancestry of plants prevented him from reaching his objective. He carried botanical description as far as the general state of knowledge of the time would permit, but his general arrangement of plants is lacking in recognition of broad relationships and by Vines is spoken of as "hap-hazard for the most part" and "far inferior to that of Cesalpino." In the *Pinax* he gives about six thousand plant names. As a predecessor of Linnæus, he is noteworthy for supplying all plants with two names and thereby marking a distinction between species and genus. "Every plant has with him a generic and a specific name, and this binary nomenclature which Linnæus is usually thought to have founded, is almost perfectly maintained by Bauhin, especially in the *Pinax;* it is true that a third and fourth word is not infrequently appended to the second, the specific name, but this additional word is only an auxiliary." (Sachs.)

Jung took a step in another direction, emphasizing morphology in his introduction to theoretical botany (*Isogogæ phytoscopia,* published in 1678, after his death). He was a very critical observer with a fine university training, and he devised a system of terminology for the parts of plants which was afterwards employed by Linnæus. Jung's contribution was very important, although it made no immediate impression; "it powerfully influenced later development; it is the foundation upon which the whole superstructure of plant morphology and descriptive botany has since been erected." (Vines.)

It was not possible to establish a natural system until long after Linnæus, when the dogma of constancy of species was over-

thrown and a knowledge of embryology was introduced; nevertheless, Caspar Bauhin recognized the fact of natural affinity as the very foundation of a natural system. Cesalpino had expressed the same view before Bauhin and pointed to the organs of fructification as the most important marks for recognizing natural affinity, and, after Bauhin, Jung had begun a systematic study of the morphology of plants.

The three men mentioned above were those from whom Linnæus drew heavily — from Cesalpino his general philosophical principles, from Bauhin his binary nomenclature, and from Jung his terminology for the parts of plants.

FIG. 111. — JOSEPH PITTON DE TOURNEFORT, 1756–1808. (Published by Dr. Thornton, 1802.)

Tournefort (1650–1708) graduated in medicine from the University of Montpellier and became Professor of Botany at the Jardin du Roi. He took a backward step by basing his classification on the external form of plants. He neglected the excellent researches of Malpighi and Grew on the structure of flower and seed, and his system, founded largely on the form of the corolla, was thoroughly artificial. He drew attention to genera and neglected species — a proceeding in contrast with that of Bauhin who described species carefully and paid little attention to genera.

RAY

When Ray and Willughby formed their scientific partnership (cf. Chapter XIV), Ray elected to give especial attention to plants. He had traveled, collected plants, and observed widely in the field. Upon the foundation of a good university training he had developed the habit of thoroughness, and, by training,

experience, and natural tastes, he was well fitted to write a treatise on botany. He appreciated the good work of his predecessors and "joyfully" acknowledged their contributions by name; at the same time he was no servile imitator but added observations and reflections of his own.

Ray published several works on botany, but his place in the history of science is mainly fixed by his comprehensive work entitled *Historia generalis plantarum* which in three folio volumes without illustrations was published in the years 1686, 1688, and 1704. This vast work enumerates and describes all the plants known to the author or described by his predecessors, to the number, according to Adamson, of 18,625 species. It includes more than a description of plants. Book I begins with a general account of plants and contains a summary of all knowledge of anatomy and physiology of vegetables, based on the work of Cesalpino, Grew, Malpighi, Jung, and others. He cites these authors and makes current many of their most important views. This part of his work appeared so important to Cuvier and Dupetit-Thouars that they advocated the republication of it separately. Ray adopted, at first (1686) with reserve, the idea expressed by Grew that sex is exhibited in plants, saying: "This opinion of Grew, however, of the use of the pollen before mentioned wants yet more decided proofs; we can only admit the doctrine as extremely probable," but in 1694, he clearly admits the sexuality of plants. He changed his views of the parts to be used in classification, at first fixing attention on the fruit as Cesalpino had done, and, later, on the flower, following Bachmann and Tournefort. Ray perceived some of the larger relationships before de Jussieu, "but not so well." In describing trees and herbs he distinguishes for the most part between mono- and dicotyledons — terms which he brought into use — but in many cases he failed to recognize this broad distinction in particular plants. With many mistakes in details, nevertheless on the whole, Ray represents the best attempt before Jussieu to base a classification on natural affinities.

It has already been noted that Ray gave the first carefully

considered definition of species and thereby laid the foundation for the consideration of the origin of species, which became a burning question in the second half of the nineteenth century.

The progress of botany during the period under consideration has been treated in detail by Sachs in his admirable *History of Botany,* which is limited in its range to three hundred thirty years — from 1530 to 1860. The story naturally falls under three subdivisions: (1) Progress in reference to the classification of plants; (2) in reference to the structure of plants; (3) in reference to vegetable physiology. In a general history of biology, however, it will be possible only to pick out general tendencies and to point to certain hindrances inherent in the state of knowledge of the times; accordingly, in this chapter we treat in barest outlines of the three aspects just mentioned.[1]

PROGRESS IN THE CLASSIFICATION OF PLANTS

LINNÆUS

An account of the life of Linnæus and his contributions especially to zoölogy has been included in chapter XIII. The view is often expressed that Linnæus marks the beginning of a new epoch in botany; Sachs, however, makes the point, which seems justified, that Linnæus is the last link in the chain of development formed by the work of Cesalpino, Bauhin, and Jung. He transmitted the work of these men and in many cases their errors. Linnæus marks not the beginning of a new epoch but the conclusion of an old one; he gathered all that was serviceable from his predecessors, adopting what the systematists had added to the ideas of Cesalpino, gave it unity and fashioned it into a system without adding anything essentially new. While he contributed essentially to the recognition of the work of his predecessors his "overwhelming importance lies in the skilful way he gathered and fused into one the scattered fragments of

[1] Through courtesies of the John Crerar Library, most of the original treatises have been available for examination, but in what follows I have drawn largely from Sachs' account, and the sentences which appear in quotation marks are, for the most part, taken from his *History of Botany.*

the past." When he came to make his own classification of plants, he devised an artificial system based on the number, arrangement, and fusion of the stamens. Although the pollen is a sexual element it should be carefully noted that his use of the

FIG. 112. — LINNÆUS IN HIS LAPLAND DRESS. (*Acta horti Bergiani.* From a painting by Mart Hofman.)

stamens in his system is not, as is so frequently stated, the recognition of the sexuality of plants. His system is commonly designated as the "sexual system of plants," but he takes his characters not from the function but from the number and mode of union of the stamens and their relation to the style.

By his great clearness of mind Linnæus imparted life and

fruitfulness to the work of his predecessors. "This freshness of life often misled his successors into believing that Linnæus thought out and discovered everything himself, but he was not an original investigator." "Linnæus," says Sachs, "never made a single important discovery throwing light on the nature of the vegetable world. On the whole, the superiority of Linnæus lay in his natural gift of discriminating and classifying objects which engaged his attention." He was a reformer of the art of description; he adopted the binomial nomenclature and made it the common property of science.

As early as 1738 (in his *Fragmenta methodici*), Linnæus had maintained that the construction of a natural system was the most desirable aim of botany, but he was so overwhelmed with the difficulties of formulating such a system, that he used artificial marks for classifying plants. In his letters Linnæus acknowledged that the construction of a natural system was beyond his powers, but botanists of France, such as A. L. de Jussieu and A. P. de Candolle, undertook the task. Until the middle of the nineteenth century, however, there was ignorance of the principle upon which such a classification could be founded. As Miall says in his *History of Biology:* "The fact is that a natural classification always rests on one and the same property, *viz.*, *affinity, i.e.*, relative nearness of descent from some common ancestor." So long as species were regarded as constant entities, standing separate, it was not possible to establish genuine affinities, and all men working under the dominance of the dogma of constancy of species were unable to construct a natural system.

It is no easy matter to estimate the influence of Linnæus on the progress of botany, and conflicting opinions have been expressed on this point by modern botanists. He seems to have exerted a direct influence which retarded the development of botany as a science, and an indirect, but more progressive, influence which he shares with Ray and others. Theoretically, he regarded the construction of a natural system as of prime importance, but in practice, as we have seen, he employed an artificial method and handed it along in his many publications.

He was fully aware that his system was merely a convenient device for finding the names of plants; in writing to Haller he says, "I never pretended that the method was natural." Most of the botanists of England, Germany, and Sweden adopted the artificial method of Linnæus, and it is a significant fact that after 1750, botany as a science degenerated in the hands of those who took Linnæus as their model. His idea of the work of the botanist was faulty and retarded progress; he taught that the rank of a botanist was to be determined by the number of plants he was able to name. Those who advanced scientific botany repudiated this teaching as well as his artificial method and sought to discover natural affinities by other means.

There remains the question: Was Linnæus genetically connected with the progress towards a natural classification which began in France with the de Jussieus and, in the period under consideration, culminated in the great English botanist, Robert Brown, — who in method and spirit was anti-Linnæan? Linnæus had formulated his artificial system of classification as a matter of convenience for determining the names of plants, but in his "Fragmenta," published in his *Classes plantarum,* in 1738, and later in his *Philosophia botanica* in 1751, he had announced different principles and left a tentative list of sixty-seven natural families of flowering plants. This is the most scientific contribution of Linnæus to the classification of plants. Was it also an indispensable help to B. de Jussieu?

In the Éloge of Bernard de Jussieu at the French Academy in 1777, it is stated that he founded his arrangement of plants on the "Fragmenta" of Linnæus, but Professor Vines thinks that it was founded on the "Methodus" of Ray, which was published earlier. At any rate Jussieu's arrangement of plants was embodied in the "Methodus" of Ray; although the "Fragmenta" of Linnæus may have helped them, the work of the Jussieus would have proceeded without it. In 1738, Linnæus had visited B. de Jussieu in Paris, and their conversations about botanical matters were doubtless mutually helpful. After the middle of the eighteenth century systematic botany took two

directions; one, based on the artificial system of Linnæus, was retrogressive; the other, in France, was progressive and was as likely based on Ray's " Methodus " as upon the " Fragmenta " of Linnæus.

As far as actual progress is concerned, the period from Linnæus to Schleiden is characterized by attempts to formulate a natural system, but we must keep always in mind the existence of certain hindrances in the state of knowledge of the time which prevented the attainment of this end. 1. As previously stated, natural affinities were sought under the dominance of the idea of constancy of species. 2. Morphology, or investigation of structure, was based on an examination of mature forms, and a knowledge of embryology was lacking. 3. Little attention was paid to the lower plants (cryptogams) which, as in the case of the lower animals (protozoa) are so important for attaining a knowledge of the higher and more modified forms.

The representative botanists of this period are Antoine L. de Jussieu, Gærtner, de Candolle, and Robert Brown.

THE DE JUSSIEU FAMILY

The de Jussieu family has a distinguished place in the history of botany from 1708, when Antoine de Jussieu went to Paris to succeed Tournefort as professor of botany at the Royal Garden, until 1853, when Adrien de Jussieu died without leaving a male descendant to carry on the succession. During these years, five members of the family, all educated as physicians, contributed to botanical progress. The de Jussieus represented a progressive tendency in botany; they followed a different and more secure path than that of the English, German, and Swedish botanists of the time, who generally adopted the artificial system of Linnæus. The French route led into the broad road of progress while the path of the others led to barren wastes. The two members of the de Jussieu family to receive notice here as especially helping towards a natural system are Bernard (1699–1777) and Antoine L. (1748–1836), uncle and nephew.

Bernard de Jussieu, was, intellectually, the peer of any other member of the family. One example of his scientific insight was shown in his recognition of the true nature of polyp-like animals. Some years before the publication (1744), of Trembley's famous monograph on the fresh water polyp, he maintained, on the basis of his own observations, that polyps and corals were animals and not flowers of marine plants which at that time was the prevailing view. His extreme modesty, however, led him to accept, in 1722, the position of sub-demonstrator of plants at the Jardin du Roi, and to decline the offer of the Professorship of botany made vacant by the death of his older brother in 1758. Although he read several papers before the French Academy of Sciences, to which distinguished body he had been elected, his indifference to public notice led to little publication of his own work. He had an eye for the good work of others and in 1725 he brought out a new edition of Tournefort's *History of Plants about Paris*. He arranged the plants in the garden of the Petit Trianon at Versailles according to his own scheme of classification founded on the "Methodus" of Ray and the "Fragmenta" of Linnæus. Bernard did not publish this arrangement, but in 1789 his nephew included it in his *Genera of Plants* and assigned to it the date of 1759.

FIG. 113. — BERNARD DE JUSSIEU, 1699–1777. (*Les Savants Modernes.*)

The nephew, Antoine L. de Jussieu, was trained under his uncle. He was rather prolific in publication and is the most widely known member of the family. He was Professor of Botany in Paris from 1770 to 1826, but during the disturbed conditions of the French Revolution he was assigned to the

charge of the hospitals of Paris. He took an active part in organizing the Museum of Natural History on its present footing and "selected for its library everything relating to natural history from the vast materials obtained from the convents then broken up." This in itself was a discerning service to science.

In 1789, A. L. de Jussieu had published "*The Genera of Plants Arranged According to Natural Orders, by the method employed in the Royal Garden at Paris*" (*Genera plantarum secundum ordines naturales disposita, juxta methodum in horto regio Parisiensi exartem*), thus recognizing in the title the work of his uncle Bernard. De Jussieu's "Orders" were collections of genera such as we now call families; he gave these groups distinctive characters and thus arrived at a higher grade of constructive reasoning than any of his predecessors. Giving distinctive characters to his "Orders" was the chief lasting contribution of A. L. de Jussieu. Says Sachs: "It might appear that the merit of Antoine de Jussieu is rated too low, when we praise him chiefly and simply for providing the families with characters; but this praise will not seem small to those who know the difficulty of such a task; very careful and long-continued researches were necessary to discover what marks were the common property of a natural group." It is not uninteresting in this connection to note "how Bauhin first provided the species with characters and named the genera but did not characterize them, how Tournefort next defined the limits of the genera, how Linnæus grouped the genera together, and simply named these groups without assigning to them characteristic marks, and how

FIG. 114. — ANTOINE L. DE JUSSIEU, 1748–1836. (Published by Dr. Thornton, 1803.)

finally Antoine Laurent de Jussieu supplied characters to the families which were now fairly recognized. Thus botanists learnt by degrees to abstract the common marks from like forms; the groups thus constituted being constantly enlarged, and inductive process was thus completed which proceeded from the individual to the more general."

This work of A. L. de Jussieu became the foundation for further advances in the natural method of classification. His fifteen classes were divided into about one hundred orders; he detected some of the marks of natural affinity in mature forms but like others he was greatly hindered by lack of knowledge of embryology and of the lineage of plants. He attributed much of the success of his system to Tournefort, "but," says Vines, "it is clear he owed at least as much to Ray."

Between 1802 and 1820, he published a number of monographs on different families of plants. In 1826, ten years before his death, he was succeeded by his son, Adrien, who had no male descendant, and with whom the brilliant botanical dynasty of the de Jussieus terminated.

GÆRTNER

Joseph Gærtner (1732–1791), says Sachs, "gives us tne impression of a modern man of science more than any other botanist of the eighteenth century, with the exception of Koelreuter. He knew how to communicate with clearness of language and perspicuity of arrangement whatever he gathered of general importance from each investigation." The publication of his work on the Fruits and Seeds of Plants (*De fructibus et seminibus plantarum*) began in 1788, the year before the appearance of de Jussieu's *Genera plantarum,* and was continued in 1791 and in 1805. With an extensive knowledge of fruits and seeds, Gærtner carefully described and figured more than a thousand kinds. In addition to other new points of view, he showed that the spores of cryptogams were essentially different from the seeds of flowering plants, and that dry indehiscent fruits were not naked seeds. His great comparative study of the

organs of propagation became a standard source of knowledge. The work had no immediate influence, but its quality, extent, and comparative method supplied a basis that could be employed later as a help in formulating a natural system of plant classification. For the most part it was neglected in Germany but was appreciated in France and used by A. L. de Jussieu and by de Candolle — as also in England by Robert Brown.

DE CANDOLLE

Augustin Pyramus de Candolle (1778–1841) built on the foundation of A. L. de Jussieu and others, but added constructive ideas of his own, and improved the principles of natural classification. He reached a higher point than his predecessors in the classification of plants. He was born in Geneva, Switzerland, and attended the university of that city, showing aptitude for studies in language and literature. He was inspired by the teachings of Vaucher to adopt botany as the chief pursuit of his life. Between the ages of eighteen and twenty-eight he lived in Paris where he made the acquaintance of the brilliant group of naturalists connected with the Jardin des Plantes and the Museum of Natural History. To a certain extent he absorbed their methods and their point of view regarding investigation of nature. At one time he served as the Deputy of Cuvier at the Collège de France, and he was intrusted by Lamarck with the honorable responsibility of bringing out a new and enlarged edition of the *Flore Française*. After ten years in Paris he

FIG. 115. — AUGUSTIN PYRAMUS DE CANDOLLE, 1778–1841. (*Acta horti Bergiani.*)

went to Montpellier, where he held the post of professor of botany, at first in the medical faculty, and later in the faculty of science. At the age of thirty-eight de Candolle returned to his native city, and soon after (1817), he was made professor of botany in the University of Geneva and Director of the Botanical Garden. Thus he returned to Geneva as a ripe student of broad training, having several published works to his credit and a wide acquaintance with the leading naturalists of France. He was succeeded by his son, Alphonse de Candolle, who carried on the botanical work of the father, also in collaboration with his son, Anne Casimir de Candolle.

While at Montpellier, Augustin Pyramus de Candolle had published an important work on the theory of botany in which he lays down the principles of classification already foreshadowed by him in his introduction to the *Flore Française* of Lamarck. The long title of this theory of botany indicates in a way its scope and purpose, to wit: "Elementary theory of botany, or an exposition of the principles of classification and the art of describing and of studying plants." It was first published in 1813, while he was at Montpellier, and later in an improved edition in 1819. De Candolle was opposed to the artificial system of Linnæus and he sought earnestly to construct a natural system and to put it into practice. He employed comparative observations on structure as the basis and sought to discover natural affinities on a so-called plan of Symmetry. His general point of view is shown in his dictum: "The whole art of natural classification consists in discovering the plan of symmetry." He attempted to find this plan of symmetry by the way of morphology. His observations were extensive and he showed with specific illustrations, that the symmetry is obscured by alterations in the parts of plants, so that, through changes, the same organs become difficult to recognize as equivalent parts. This was a study of what we now call homologies.

The three causes which tend to produce changes are designated as abortion of parts, degeneration of parts, and adherence of parts of one kind to parts of another kind. De Candolle

gives copious illustrations to show his meaning, but, in a general history such as this book, there is no need of going into these details.

Having laid down general principles in his "*Théorie*," he projected on a vast scale a work on systematic botany. He began his *Regni vegetabilis systema naturale*, and after publishing two volumes of it, 1818–1821, realized that it was too great an undertaking to be carried out in a single lifetime; accordingly, he placed stricter limits on the project and changed the name tc *Prodromus systematis naturalis regni vegetabilis*, etc., but even of this he lived to complete only seven volumes. The publication of the *Prodromus* extended over a period of forty-nine years, from 1824 to 1873, and was completed in seventeen volumes thirty-two years after the death of its principal author. This vast work is made up of the contributions of several botanists, but the work as to design was the product of the brain of Pyramus de Candolle, and he contributed much more in number of published pages than any other person.

After his death it was continued by his son, Alphonse de Candolle, as editor and part author. In the last volume of the work, Alphonse de Candolle makes a summary showing the number of printed pages contributed by each of the different collaborators. The text without indices comprises 12,038½ pages, of which Pyramus contributed 4303½; Alphonse, his son, 1387; and Casimir, his grandson, 259½ pages. Eleven other contributors are mentioned: Müller supplying 1144½ pages of text; Bentham, 1133, and Meisner, 835. The other authors are credited with from two hundred twenty-one to seven hundred thirty-two pages each. This prodigious work was highly esteemed as a standard reference for flowering plants, and in a way it is still used with the necessary modifications to make it conform with the progress of knowledge.

The almost extravagant praise of de Candolle by Sachs, whose words are indefinite as to the amount of the work to be attributed to others is as follows: "The amount and compass of de Candolle's labors as a systematic and descriptive botanist exceed

those of any other writer before or after him. He wrote a series of comprehensive monographs of large families of plants, and published a new edition of Lamarck's *Flore Française* substantially altered and enlarged; and in addition to these and many similar works and treatises on the geographical distribution of plants, he set on foot the grandest work of descriptive botany that is yet in existence, the *Prodromus systematis naturalis,* in which all known plants were to be arranged according to his natural system and described at length — a work not yet fully complete, and in which many other descriptive botanists of the century participated, but none to so large an extent as de Candolle, who alone completed more than a hundred families. It is not possible to give an account in a few words of the service rendered to botany by such labors as these; they form the real empirical basis of general botany, and the better and more carefully this is laid, the greater the security obtained for the foundations of the whole science."

De Candolle's work is an essential link in the progress of classification of plants. In the period under discussion, he and Robert Brown were the foremost men in systematic botany, and we now turn to the labors of Robert Brown as a systematist.

ROBERT BROWN

The eminent English botanist, Robert Brown, lived in a transitional period, when the old was giving way to modern aspects of botany — a period before the overthrow of the dogma of constancy of the species; a period in which embryology as a method of investigation was emerging (a movement in which he had a part); a period in which the importance of the cryptogams was beginning to be recognized. His period of greatest productivity was prior to publication of the far-reaching studies of de Bary on cryptogams and of Hofmeister on the embryology of plants. He died in 1858, the year before the publication of *The Origin of Species*. During his life, however, biological advances of the greatest importance were in progress; von Baer, in 1828, had laid the foundations of the embryology of animals;

Schleiden had reformed the teaching of botany; von Mohl had published his researches in plant morphology; Johannes Müller had issued his notable work in physiology; and the cell-theory had been formulated by Schleiden and Schwann.

Robert Brown (1773–1858, Fig. 116) was an example of a man of great intellectual gifts sharpened and intensified by fine scientific training; he was thorough, incisive, methodical, and cautious. His work was circumscribed by the state of knowledge of the time but so well done that it required little modification with the advance of knowledge in after years.

Fig. 116. — Robert Brown, 1773–1858. (Lithograph from a photograph.)

He was the son of a non-juring Scottish minister, who became Bishop of the religious flock which followed him when he left the main body of the Church. Robert Brown inherited the independence and sturdy character of his father with the canny qualities of Scottish stock. Having studied medicine, he was for six years surgeon's mate of a British Regiment quartered in Ireland. From early years he showed a love of botany, and while connected with the army he collected and studied plants so assiduously that he became known as a naturalist.

In 1798 he visited London to inspect collections of natural history and met Sir Joseph Banks, the President of the Royal Society, whose kindly disposition towards scientific men helped along many a research. Sir Joseph was greatly attracted to the young Scot, and as a protégé of that explorer, collector and man of wealth, Brown's scientific interests and worldly prospects were advanced. In 1801 he sailed as naturalist on a scientific expedition to Australia and New Zealand — a post to which he had

been nominated by Sir Joseph. Returning to England in 1805 with a collection of four thousand plants, many of which were new to science, he thereafter devoted himself to botany with light duties as a librarian for his support. As librarian of the Linnæan Society from 1805 to 1822, and of Sir Joseph Banks after 1810, he had opportunities to carry on his botanical studies with few distractions. Preferring to remain in London where he had the use of extensive collections, including those of Linnæus and of Banks, Brown declined university positions offered at Edinburgh and Glasgow.

On the death of Sir Joseph Banks, in 1820, Brown inherited his house in Soho square with the specified use during his life of the collections and library. In 1827 the Banks collection and library were transferred to the British Museum and by mutual understanding this secured to Brown for life a position in the British Museum as keeper of the botanical collections. With his sagacity, his mental incisiveness, his industry and his well-directed efforts, he attained high rank in science and came to be recognized as the foremost botanist of his time — "*Botanicorum facile princeps*" as von Humboldt said of him.

Brown's investigations were well thought out and matured before they were printed. It should be remembered that he had observed plants extensively in the field and had taken notes on the spot, so that his writings have the stamp of reality with the freshness and vigor of personal familiarity with plants in their living state.

In 1810 appeared his "*Prodromus*" of the Flora of Australia and New Zealand. Of this work only one volume was published embracing descriptions of about two thousand plants many of which were described for the first time. He used a remodeled form of de Candolle's method. He also published a series of monographs, extending over a number of years, on different groups of plants, those on the Orchids and the Asclepiads, on Kingia, on Cycads and Conifers, and on Rafflesia, being the most famous. Most of his botanical writings, omitting the "*Prodromus*," were collected and published in two volumes of text and

one volume of plates, by the Ray Society, 1866–1868, in convenient form for consultation.

It was a characteristic of Brown's writings to contain digressions not immediately connected with the main topic of his memoir, and it is in these incidental digressions that we find some of his most important discoveries — such as the nature of fertilization, the nucleus of the plant-cell, the movement of protoplasm, the " Brownian " movement, etc.

In 1831, in his studies on the Asclepiads, he observed the entrance of the pollen tube into contact with the ovule and discovered the nature of fertilization. He perceived the gradual formation of the embryo after fertilization and he advocated the study of development as a means of interpreting the mature structure — anticipating the extensive use of embryology which became general in botany only after the notable researches of Hofmeister.

Brown described the cell nucleus in his *Observations of the Organs and Mode of Fecundation in Orchideæ and Asclepiadeæ* and since this observation is of historical importance in connection with the rise of the cell-theory, it is worth while to quote the main part of his description. The memoir was published in the Transactions of the Linnæan Society for 1833, but had been previously printed for private distribution in October, 1831. Working with a simple lens of one-third inch focal length, he observed the nucleus at first in the epidermis of orchids and afterward extended it to other plants.

He says (p. 511): " I shall conclude my observations on Orchideæ with a notice of some points of their general structure, which relate to the cellular tissue. In each cell of a great part of this family, especially of those with membranaceous leaves, a single circular areola, generally somewhat more opaque than the membrane of the cell, is observable. This areola, which is more or less distinctly granular, is slightly convex, and although it seems to be on the surface is in reality covered by the outer lamina of the cell. There is no regularity as to its place in the cell; it is not unfrequently, however, central or nearly so. . . .

This areola, or nucleus of the cell as perhaps it might be termed, is not confined to the epidermis, being also found not only in the pubescence, . . . but in many cases in the parenchyma or internal cells of the tissue. . . . In the compressed cells of the epidermis the nucleus is in a corresponding degree flattened, but in the internal tissue it is often nearly spherical. . . .

" The nucleus of the cell is not confined to Orchideæ, but is equally manifest in many other Monocotyledonous families; and I have found it, hitherto however in a few cases, in the epidermis of Dicotyledonous plants. . . . In some plants, especially in Tradescantia Virginica and several nearly related species, it is uncommonly distinct, not only in the epidermis and in the jointed hairs of the filaments, but in the tissue of the stigma, in the cells of the ovulum even before impregnation, and in all the stages of formation of the grains of pollen, etc.

" The few indications of the presence of this nucleus, or areola, that I have hitherto met with in the publications of botanists, are chiefly in some figures of epidermis, in the recent works of Meyen and Purkinje, and in one case in M. Adolphe Brongniart's memoir on the structure of leaves. But so little importance seems to be attached to it, that the appearance is not always referred to in the explanations of the figures in which it is represented."

Brown's account of a new genus christened Rafflesia (in honor of Sir Stamford Raffles) contains comments which are still of general interest. This genus was founded on the gigantic flower of Sumatra which measures " a full yard across " and was designated by Dr. Arnold, its discoverer, as " the greatest prodigy of the vegetable world."

Robert Brown had wide general influence on the improvement of botanical investigation; he succeeded in clearing up the morphology of the flower and in advancing the natural system of classification. Perhaps his most notable single discovery was recognizing the peculiar structure of the flowers of Conifers and Cycads as compared with those of other flowering plants. Previously the Conifers and Cycads had been grouped with the

Angiosperms on the belief that their seeds were really seed cases. Brown demonstrated that there are no seed cases in these plants but that their seeds are naked, and this led to the establishment of the group of Gymnosperms, or plants with naked seeds, in contrast with the Angiosperms, or plants with seeds enveloped in some sort of covering.

Sachs says of this discovery: " Thus one of the most remarkable facts in vegetation, the gymnospermy of the Conifers and Cycads, was for the first time established, and this led afterwards through Hofmeister's investigations to the important result, that the Gymnosperms, which had been up to that time classed with Dicotyledons, are to be regarded as coördinate with Dicotyledons and Monocotyledons, forming a third class through which remarkable homologies were brought to light in the propagation of the higher Cryptogams and the formation of seeds in Phanerogams. No more important discovery was ever made in the domain of comparative morphology and systematic botany. The first steps towards this result, which was clearly brought out by Hofmeister twenty-five years later, were secured by Robert Brown's researches."

Asa Gray, the American botanist, made the acquaintance of Brown in London and expressed his admiration in various tributes, one of which is as follows: " Brown delighted to rise from a special case to a high and wide generalisation, and was apt to draw most important and almost irresistable conclusions from small selected data, or particular points of structure, which to ordinary apprehension would appear wholly inadequate to the purpose. He had unequalled skill in finding decisive instances. So all his discoveries, so simply and quietly announced, and all his notes and observations, sedulously reduced to the briefest expressions, are fertile far beyond the reader's expectation. Cautious to excess, never suggesting a theory until he had thoroughly weighed all available objections to it, and never propounding a view which he did not know how to prove, perhaps no naturalist ever taught so much in writing so little, or made so few statements that had to be recalled or even recast."

With Brown we come to the threshold of a new kind of botanical investigation, and of botanical teaching, inaugurated by the work of Hofmeister, of Schleiden and a number of other brilliant investigators of the period — a further development of botany which will be considered in a separate chapter.

CHAPTER XVIII

PLANT ANATOMY, HISTOLOGY AND PHYSIOLOGY FROM LINNÆUS TO SACHS

PROGRESS IN VEGETABLE ANATOMY

In the period under consideration the chief studies of vegetable anatomy were directed towards determining the inner structure of plants. This involved the use of the microscope, and towards the last of the period, these investigations were aided by the introduction of new methods of technique. Microscopic studies extending over a long period slowly advanced towards the recognition of separate tissues and their origin. The end-results were the formulation of the cell-theory, the recognition of protoplasm as the essential constituent of the cell, determination of the nature of cell-formation, and the conception of the growth of organic matter by intussusception.

The gradual growth of scientific thought about the minute structure of plants and the nature of their cellular elements is such an involved story, that when its details are considered it is adapted only to a special history of botany. The story must be treated either summarily or in considerable detail; here we shall attempt to give only the broad outlines of the subject.

MALPIGHI AND GREW

The foundation of the microscopic anatomy of plants was laid by Malpighi and Grew in the last quarter of the seventeenth century. We pass over Hooke's observations on cellular structure of cork and other vegetable products published in 1665. These were merely incidental observations mixed with a mass of other work published in a book devoted to revelations of the microscope. In his *Micrographia* Hooke was not concerned

especially with plants; on the other hand, the books of Malpighi, *Anatome plantarum,* and of Grew, *The Anatomy of Plants,* were primarily treatises on the structure of plants.

On the eighty-eight copper plates of Malpighi's treatise there are four hundred seventy-eight illustrations but not more than fifty or sixty of these exhibit histological structure. The other illustrations chiefly show the coarser anatomical features of root, stem, leaves, flowers, together with pictures of germinating seeds, simple sketches of the growth of plant embryos, etc. Now since Malpighi's text is substantially a description of the pictures, this list conveys a general idea of the topics treated in his *Anatome plantarum.*

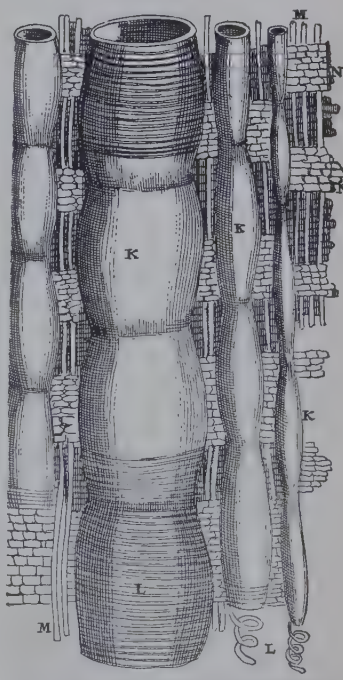

FIG. 117. — MICROSCOPIC STRUCTURE OF OAK WOOD. (Malpighi, *Anatome plantarum,* 1679.)

By pictures of thin sections examined under the microscope he illustrates cells and vessels of plants, but he considers cells — which he calls "utriculi" — as a massed matrix rather than as elementary units of structure. Fig. 117 shows his picture of the microscopic structure of oak wood (*"roboris et quercus"*). It is a suggestive picture and for a moment seems to imply that here we have the beginning of the cell-theory, but an examination of the text shows us that all the sketches are nothing more than representations of what he saw under his microscope.

Fig. 118 shows a single row of "utriculi" joined end to end, forming a spine on the surface of a gourd (*curcurbitæ*). He says

plants of this kind are provided with spines on the stem, flowers, and leaves and he illustrates the appearance of the spines when magnified. He observes that the spine has a group of small cells (*utriculi*) at the base, and that within the cells of the spine proper there is "an abundant clear liquid (*intus diaphanus luxuriat humor*) which sometimes exudes from the terminal end." Malpighi, however, is more concerned about the vessels and fibres of plants and their course through the plant tissue. He observes different kinds of vessels, those that carry air, sap, milk, etc., the "utricles" differing in size and shape seem to him a part of the matrix within which run the fibres and vessels. On a supposed analogy with animal structure (of which his knowledge was extensive) he designates air-vessels "breathing tubes or tracheæ" which (erroneously) he thinks contract and expand. Malpighi was inclined toward physiology and his anatomical ideas are related in his mind to the use of the structures.

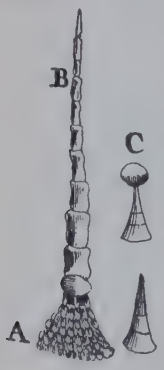

FIG. 118.—CELLS (UTRICULI) IN A SPINE OF THE GOURD. (Malpighi, op. cit.)

As mentioned a moment ago, we must guard against the idea that he was on the verge of conceiving the cell-theory and of regarding the cell as the primary element of structure. Since he sketches the appearance of cells in plant tissues he was one of the pioneer observers of cells but, at most, his observations were merely vague foreshadowings of the cell-theory of Schleiden and Schwann. This applies also to the observations of Hooke, of Leeuwenhoek, and of Grew.

Grew's figures of microscopic anatomy of plants were more numerous and better drawn than those of Malpighi. In his complete treatise, *The Anatomy of Plants* (1682), there are eighty-two plates containing about five hundred forty sketches engraved on copper; eighty-seven of these show microscopic structure. So far as scientific production is concerned, Grew was almost solely [1]

[1] He published lectures delivered before the Royal Society on chemistry and solutions. In 1681, he printed "on request" a catalogue and description of the

a plant anatomist; the chief work of his life was producing *The Anatomy of Plants,* while Malpighi besides his treatise on plants was notable for much anatomical and physiological investigation with animals such as the embryology of the chick, the anatomy of insects, the structure of the lungs, secreting glands, the spleen, skin, the discovery of blood capillaries, etc. Malpighi has a more important place in the history of biology, but as regards illustrations of the microscopic structure of plants Grew is superior to Malpighi.

Nehemiah Grew (Fig. 119, 1641–1712) began observations of the structure of plants at the age of twenty-three, seven years before he took the degree of M.D. at Leyden. His first publication on the subject, *The Anatomy of Vegetables Begun,* appeared in 1671, and in 1682 his completed and revised observations were published by the Royal Society under the title *The Anatomy of Plants, Etc.* He says that his observations were "prosecuted with the bare eye and with the microscope." Like Malpighi his mind is more concerned with the vessels and fibres of plants than with the cells — the latter he speaks of as "bladders."

Fig. 119. — Nehemiah Grew, 1641–1712. (Published by Dr. Thornton, 1804.)

Malpighi is content with representing the microscopic structure in a small shaving and is never lavish with structural details. Grew is more elaborate in making his pictures — often he laboriously fills out the entire surface of the cross-section of a stem, making a large, handsome, and symmetrical figure.

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natural and artificial Rarities belonging to the Royal Society and preserved at Gresham College; three hundred eighty-six folio pages, twenty-one plates. To this catalogue was subjoined his illustrated memoir with the now inelegant title, "The Comparative Anatomy of Stomachs and Guts Begun." In his old age he published *Cosmologia Sacra* (1701).

As shown in Fig. 120, Grew attempted reconstructions, working out in its various dimensions the structure of the stem considered as a solid.

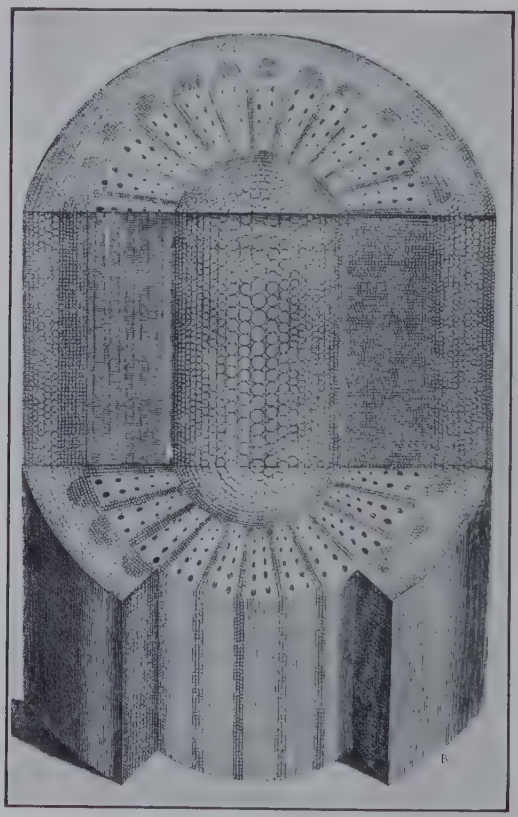

FIG. 120. — MICROSCOPIC STRUCTURE OF A VINE PLANT, CONSIDERED AS A SOLID. (Grew.)

Fig. 121 shows a much reduced reproduction of his picture of the microscopic structure of sumac wood. This represents somewhat less than one-third of a complete cross-section of the stem; but there are four plates in his treatise that show cross-

sections of other plants completely filled out and making pictures too large to represent here. In all there are about forty-five figures showing histological details.

The writings of Malpighi and Grew on the structure of plants appeared almost simultaneously. On the very day (Dec. 7,

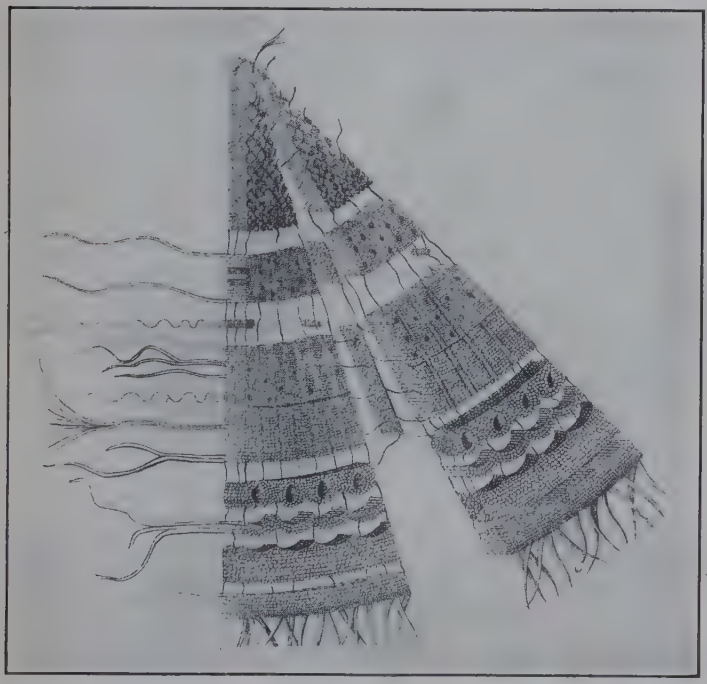

FIG. 121. — MICROSCOPIC STRUCTURE OF A SUMAC STEM. MUCH REDUCED. (Grew, 1682.)

1671) that the Royal Society received in print Grew's first essay, *The Anatomy of Vegetables Begun*, the Secretary reported the receipt of Malpighi's manuscript dealing with the same subject, and which in 1675 was published by the Royal Society under the title *Anatomes plantarum idea*. Both men continued to make observations on the structure of plants. The revised and much

extended work of Grew, entitled *The Anatomy of Plants* (1682) contains four books, with two hundred twelve folio pages, and, as already stated, eighty-two plates with five hundred thirty-eight figures. In the meanwhile, Malpighi's observations in the same field had been printed by the Royal Society in two parts, in the years 1675 and 1679. The two parts were combined and published in 1687 in a quarto edition of his *Opera Omnia*. The completed treatise of Malpighi occupies less space than that of Grew; the *Anatome plantarum* has one hundred sixty-three quarto pages of text with eighty-eight copper plates and four hundred seventy-eight illustrations. In his writing Malpighi is more terse and not much inclined to wander away from his subject, while Grew makes digressions on many of the philosophical and religious questions of the day.

These men were independent workers and it is difficult to account for Schleiden's caustic accusation that Grew plagiarized from Malpighi. In the preface to his complete work, Grew refers to Malpighi, telling how the manuscript of Malpighi's first memoir was received by the Royal Society on the day that his contribution was published, and, in writing of "air vessels" he makes a cordial reference to Malpighi's observations saying: "The manner of their spiral conformation (not observable but by a microscope) I first learned from him (Malpighi) who hath given a very elegant description of them." In debate Schleiden was not always fair, or even careful of his facts, and it has been shown that his particular indictment of Grew is groundless. To what extent Grew may have been indebted to Malpighi is difficult to determine. In his final publication he greatly altered his earlier writing on the anatomy of plants; he quotes Malpighi in reference to the spiral thread of air-vessels and adds that he finds the thread double and not single as Malpighi had claimed, but there is no evidence that he drew from Malpighi's work without acknowledgement.

In the eighteenth century the microscopic anatomy of plants was almost wholly neglected, and Malpighi and Grew remained the recognized authorities into the early years of the nineteenth

century. The efforts of Morison, Ray, Tournefort, and Linnæus, the dominant botanists of the eighteenth century, were exerted in other directions. One investigator, however, Caspar Frederich Wolff, worked on the development of plants and animals and published the results in his well-known *Theoria generationis* in 1759, but there was no investigator of importance in this particular field between Malpighi and Mirbel. Wolff's conception of plant cells was apparently that of spaces in a homogeneous matrix. In reference to the tissues of animals, however, he formed a conception of utricles arranged in layers corresponding to the germ-layers of embryologists of the nineteenth century.[2]

Lamarck, 1809, and his younger colleague Mirbel, both gave expressions to general ideas about cells that are among the interesting anticipations of the cell-theory, but it is a mistake to consider either one as a presumptive founder of that great generalization.

During the first half of the nineteenth century the study of the inner structure of plants had been resumed. This branch of study led to more important results; it opened, indeed, many problems of general biology. Bernhardi, Mirbel, Treviranus, Moldenhawer, and Meyen made individual contributions of merit, but von Mohl and Nägeli so far surpassed all other investigators in vegetable anatomy that we may well confine attention to their scientific output.[3] It is not to be overlooked that Schleiden, in 1838, had raised embryological study to the first rank in botanical investigation, but (in the same year) his particular investigation of free-cell formation was shown to be faulty and misleading.

VON MOHL

During the first half of the nineteenth century, Hugo von Mohl was the leading plant anatomist up to Nägeli. Before he was forty years of age he was acknowledged to hold first place among the investigators of plant anatomy "decidedly superior

[2] See his *Formatione intestinorum*, 1768.

[3] Schleiden, their contemporary, although working in the same field, exerted only a temporary influence on vegetable anatomy; he was more important in another connection which will be dealt with in the following chapter.

to all rivals." Exact, broadly-trained, and sagacious, adhering strictly to the inductive method of research, his results were woven into the permanent fabric of scientific botany. By mental temper he was critical more than constructive. Slow to form conclusions and chary of theories, he did not write general surveys but confined himself to strictly scientific contributions. In contrast with Schleiden, his contemporary, von Mohl's conclusions were in the main permanent while many of Schleiden's were but temporary.

Hugo von Mohl (Fig. 122) was born at Stuttgart in 1805 into a family renowned for education and scholarship. His

FIG. 122. — HUGO VON MOHL, 1805–1872.

father was a Württemberg statesman "the family being connected on both sides with the higher class of state officials of Württemberg." One elder brother, Julius, was eminent as an

Orientalist; a still older brother, Robert, was a well-known jurist and statesman; and a younger brother, Moritz, entered official life and is remembered for publications on economic and political questions.

On graduating in medicine at Munich, with distinction, Hugo von Mohl started anatomical investigations of plants which were carried on nearly to the close of his life. His first university position was a post in physiology at Berne (1832), and in 1835 he became professor of botany at Tübingen where he remained until his death in 1872. Unmarried, he led a solitary and uneventful life devoted to science.

Having begun his university teaching in physiology, it is quite natural that he should connect his anatomical studies with physiology, but he kept a fine balance. His principal field of activity was microscopic investigation chiefly with the higher plants. He was very expert with the microscope both as an observer and in mechanical manipulations, and he made some improvements in that scientific instrument. He published monographs on the structure of plants, and his analysis of the solid framework and finally of the soft living substance of plants was very searching and laid the foundation for future work.

In his studies of the solid framework of plants he demonstrated, by exact observations, that which had been loosely held by others; he showed that the cell is the individual elementary unit of structure; he was the first (1831) to explain the formation of vessels (except "milk-vessels" and secreting tubes) in plants as produced by the union of elongated cells; he studied the growth in thickness of the cell-membrane as well as the various structural changes produced by the thickenings; in due course, he arrived at a knowledge of plant tissues, he detected the longitudinal course of vascular bundles, and distinguished the different forms of tissue entering into their composition; and he also made early studies on the chemical nature of the cell-membrane.

As a more searching line of inquiry, he observed internal phenomena and analyzed the cell-contents. He recognized pro-

toplasm as the source of the streaming movements in plant cells — this movement having previously attracted the attention of many investigators. He observed the protoplasmic lining of vacuolated cells and gave it the name of "primordial utricle" (1844). He observed the behavior of protoplasm in cell-division, and helped overthrow Schleiden's theory of free cell-formation. He brought the word protoplasm into general use (1846) although he was not the originator of the term and he recognized that the chlorophyll corpuscles are composed of protoplasm.

As indicated above, von Mohl opposed the theory of free cell-formation as held by Schleiden. In 1835 he described for the first time step by step a case of cell-division in one of the Algæ (Cladophora); this established quite securely the new idea of the origin of cells and laid a foundation for the investigation of the development of tissues which was built upon by Nägeli and Hofmeister.

His principal researches up to 1845 were assembled in a volume designated "Miscellaneous Writings" (*Vermischte Schriften*). He continued his researches, but it is of especial interest to students of the history of biology that in 1851 he gave a summary of his views on the anatomy and physiology of the vegetable cell. This small treatise of one hundred fifty-eight pages (sixty pages anatomy and ninety-eight of physiology) was not originally intended to be published as an independent book. It was prepared for Wagner's "*Cyclopædia of Physiology*" but also appeared at Braunschweig in 1851 with the title *Grundzüge der Anatomie und Physiologie der Vegetabilischen Zelle.* The following year it was published at London in English translation as *Principles of the Anatomy and Physiology of the Vegetable Cell,* and for a long time was the accepted standard of the subject. Von Mohl's investigations threw light on some of the chief biological questions of his time. He wrote only after prolonged reflection, and this with his "extraordinary carefulness" in research made many of his results endure.

NÄGELI

Carl Nägeli investigated especially the nucleus of plants, of tissue-formation, etc., and carried further the work of Schleiden and von Mohl. This keen-minded investigator was Swiss by birth and university training; born near Zurich in 1817; twelve years younger than von Mohl and thirteen years the junior of Schleiden. During the course of his education he studied botany

FIG. 123. — CARL VON NÄGELI, 1817–1891.

at Geneva under A. P. de Candolle and was graduated from the university with a botanical thesis in 1840. From the outset he devoted himself to botany and sought to ally himself with the newer botany of the period; so well was his work done that he gained recognition as one of the foremost men of science of the time. After holding preliminary positions in botany at Zurich and Freiburg, he was called as professor of botany to the university of Munich in 1857, where he remained until his death in 1891.

Although receiving an early impetus from A. P. de Candolle, who was working chiefly on the classification of plants, Nägeli was strongly drawn towards microscopical researches and studies of plant development to which his attention had been directed by Professor Schleiden of Jena. As Sachs says, he "devoted himself with energy and sound reasoning to the important and difficult question, how cells are formed in reproduction and growing vegetative organs, and how far the processes are the same in the lower Cryptogams and in the Phanerogams." He proposed a theory of cell-formation opposed to Schleiden's theory of free cell-formation, and showed that the phenomena of cell-formation are similar in the lower and the higher plants and agree in essential particulars with the cell-formation of animals as Schwann (1839) and Kölliker (1845) had already maintained.

This was a step in the fuller demonstration of the essential unity of the living substance of plants and animals. Investigations into the phenomena of cell multiplication turned attention to the living substance of cells upon which growth and cell-division depend.

The researches of Schleiden, Schwann, von Mohl and Nägeli all joined to establish the most important conclusion that all living organisms are united on a basis of similitude of structure, and that the living substance, protoplasm, is concerned with the formation of new cells. The researches of Nägeli (1841–1846) and of von Mohl (1844–1846) on protoplasm, although carried on independently, were closely related; Nägeli demonstrated that the living substance is nitrogenous matter distinct from the cell-wall, and von Mohl named it protoplasm in 1846. Both observed movements of protoplasm and distinguished between it and the cell-sap in which streaming, circulation, and rotation were formerly supposed to occur.

In addition to studies of the cell-nucleus, of algae, of cell-multiplication, and tissue-formation, Nägeli is notable for the discovery of growth from an "apical cell" in lower plants and the formation of tissues from a "meristem" in the higher. Per-

haps he is most familiarly known to the present generation of botanists for his work on the apical cell and for his profound dissertation on the structure of starch grains (1858). It was in the latter work that he developed his theory of micellar structure of organic matter and its growth by intussusception. The impulsive and enthusiastic expressions of von Sachs regarding this hypothesis are memorable as an illustration of the way in which human opinion of experts fluctuates — an ever present difficulty to the historian. Sachs speaks of this work as of " extraordinary value " and as forming " an epoch not in phytotomy only but in the general knowledge of organized bodies." He went so far as to believe that Nägeli's views represented finality on the subject.

Says Sachs, " By the application of methods of research unknown before in microscopy, Nägeli arrived at clear ideas of the molecular structure of the (starch) grains, and of their growth by the introduction of new molecules between the old ones," etc. " Nägeli's molecular theory is the first careful attempt to apply mechanico-physical considerations to the explanation of the phenomena of organic life." Notwithstanding the unqualified support of Sachs — who was perhaps the leading botanist of his time — after twenty years of dominance, the theory of Nägeli was for a time practically abandoned for the conception of growth by apposition, an older idea now revived, especially by Strasburger. This was followed by a return to Nägeli's views in a modified form, and, finally, by the conclusion of Pfeffer that both kinds of growth prevail.

Nägeli lived in stirring times for the advance of biology. Intensive studies in related subjects — embryology and animal histology (von Baer, Köelliker), physiology (J. Müller), etc. — taken in connection with the botanical investigations, provided constructive material. Many of the fundamental conceptions of biology were formulated during his life-time. He saw the establishment of the cell-theory and its union with the protoplasm-doctrine — the latter effected by Max Schultze, in 1863, but in the earlier stages of which Nägeli had a part. He witnessed the

revival of the doctrine of organic evolution in 1859, in the discussion of which he engaged in the later years of his life.

In 1884 appeared his discussion of organic evolution (*Mechanisch-physiologische Theorie der Abstammungslehre*). His theory is to be classed as one of Orthogenesis — a direct development of organisms, depending on the existence of a principle of progressive development inherent within that part of the protoplasm to which he gives the name of "idioplasm." The idioplasm, he maintains, is separate from the nutritive-plasm and forms a material basis of heredity. He repudiates Darwin's principle of natural selection. These matters are mentioned here as exhibiting a part of Nägeli's scientific activity and will be dealt with more fully in another connection under the heading of organic evolution.

We now leave the subject of advances regarding the microscopic structure of plants and turn to another aspect of plant study.

PROGRESS IN VEGETABLE PHYSIOLOGY

It was natural that the knowledge of vegetable physiology should arise slowly and should lag behind the development of animal physiology. Problems of function are more obscure than those of structure, and considerable knowledge of structure must be attained before the question of use of parts can be investigated. This applies to both animal and vegetable physiology, but in plants the physiological activities are less obvious than those of animals. Inasmuch as plants lack easily recognized organs of respiration, digestion, circulation, nervous response, etc., their physiological processes are merged together and therefore difficult to separate for individual analysis. The earlier ideas of vegetable physiology were based on supposed analogies with animal physiology and on this basis made little progress. By the middle of the eighteenth century, in the time of Haller, animal physiology had separated itself from other connections and had become an independent branch of science to be pursued for its own sake. Vegetable physiology, however, attained this

position only after the middle of the nineteenth century and then, chiefly through the work of Sachs — "the father of modern vegetable physiology."

Disregarding certain sporadic observations, the rise of vegetable physiology can be summed up by reference to the work of a few men, and we take Hales, Ingen-Housz, de Saussure, Knight, and Sachs to represent the succession. Knowledge of physiology depends, of course, on experiments devised to answer certain definite questions and we start with Hales because he was the first to lay out and follow a program of experimental investigation with plants. In this sense he laid the foundation-stone of vegetable physiology.[4]

STEPHEN HALES

We get a clue to Hales' scientific activity from his university studies and from the time in which he lived. He was a Curate and Rector of the Church of England with a scientific turn of mind, who had studied anatomy and chemistry and retained a vital interest in scientific pursuits to the end of his life. With a knowledge of anatomy, chemistry, and physics he turned his attention to physiological experiments with both animals and plants. He was unhampered by his theology, being a teleologist only in his theological thinking while in science he sought mechanical explanations. On account of the influence of Newton, the time in which Hales lived was a propitious one in England for the growth of science. Newton had published his *Principia* when Hales was ten years old and Sir Isaac lived for forty years longer, exerting a stimulating influence on all the sciences.

The bare facts of Hales' uneventful life are these: born in

[4] Before Hales' experiments in vegetable physiology there had been an occasional piece of work in this field. Mention should be made especially of Malpighi's conclusion that the leaves of plants play a part in their nutrition. "The chemist, van Helmot (1577–1644) deserves to be remembered in this connection as the author of the first recorded experiment in vegetable physiology. He planted a willow in a weighed quantity of soil and watered it with rain; in five years the plant had grown from sixteen pounds in weight to one hundred and sixty-nine, while the earth in the pot showed only a loss of two ounces. Not suspecting that the plant drew a great part of its food from the air, he was forced to exaggerate the virtues of rain-water." (Thomson.)

1677, he entered at the age of nineteen Corpus Christi[5] (then Benet) college, Cambridge, as a student preparing for the ministry. In 1703 he received the degree of Master of Arts, having in the meantime pursued anatomy, physics, chemistry, and natural history in addition to his literary and philosophical studies. In 1708–1709 he was appointed to the perpetual curacy at Teddington, Middlesex, where he remained to the end of his life, and on his death, in 1761, he was buried there under the flags of the parish church. He served also as rector of Farringdon, in Hampshire, holding the two positions concurrently. In 1711, after he had begun his ministry at Teddington, he received the degree of Bachelor of Divinity from the university of Cambridge. While not neglecting his parish work he busied himself with scientific investigations and read a number of technical papers before the Royal Society of London, by which body he was elected a Fellow in 1717. His advancement as a scientific investigator was steady and, in 1739, the Royal Society awarded him its Copley medal in recognition of the high quality of his scientific output. He was also diligent in good works as a pastor and, in 1733, was honored by the university of Oxford with the degree of Doctor of Divinity. He appears to have been a likable man well known for "constant serenity and cheerfulness of mind." He showed a spirit of public service and an interest in bettering living conditions of mankind. He helped his parish secure a good water supply and he invented a ventilator for supplying fresh air in hospitals, gaols, and shipholds.

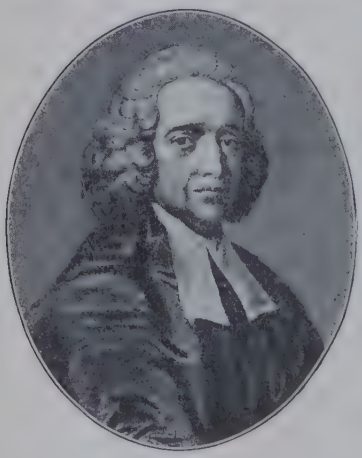

FIG. 124. — STEPHEN HALES, 1677–1761. (From a painting by F. Coates.)

[5] Not Christ's college as stated in Sachs' *History of Botany*.

When fifty years old Hales published his *Vegetable Staticks*,[6] a book of experiments with ingenious contrivances to show the "force of the sap" in vegetables and some features of the nutrition of plants. In the preface (p. 3) we learn that twenty years earlier he had made physiological experiments with animals — probably beginning before he entered on his ministry at Teddington. "About twenty years since I made several hæmastatical Experiments on Dogs, and six years afterward repeated the same on Horses and other Animals, in order to find out the force of the blood in the Arteries. . . . At which time I wished I could have made the like Experiments, to discover the force of the sap in Vegetables; but dispaired of ever effecting it, till about seven years since, I hit upon it, while I was endeavoring by several ways to stop the bleeding of an old stem of a vine." etc.

Hales was a pioneer in using instruments for the measurement of physiological activities. Sometimes his experiments were planned on an extensive scale, and we find him adopting a more modern point of view than we might expect at the time in which he worked. One of his illustrations shows three mercury gauges attached to a vine fifty feet long to measure the root-pressure, and he compares his results with the blood-pressure as determined by himself in animals. He invented one of the methods of estimating transpiration in plants that was used after 1860 by German and French investigators, and Sachs went back to Hales for results to compare with his own observations of the amount of water transpired in a given time. In his *Textbook of Plant Physiology*, published in 1881, Pfeffer recommends Hales' method of estimating the surface of leaves by covering them with a quarter-inch mesh and counting the spaces.

[6] *Vegetable Staticks:* or, an account of some statical experiments on the Sap in vegetables: Being an essay towards a Natural History of Vegetation. Also, a specimen of An Attempt to Analyse the Air by a variety of Chymio-experiments; which were read at several meetings before the Royal Society. By Stephen Hales, B.D., F.R.S., Rector of Farringdon, Hampshire, and Minister of Teddington, Middlesex, London, 1727. A small octavo of three hundred seventy-six pages; one hundred fifty-four pages being devoted to Vegetable Statics, one hundred sixty-two pages to analysis of air, and sixty pages Of Vegetation, illustrated by forty-six figures; thirty-two figures of physiological experiments, seven on analysis of the air, and seven on growth.

"One of his most important discoveries has generally been overlooked even in modern times, probably because it was entirely neglected by his successors in the eighteenth century; he was the first who proved that air coöperates in building up the body of the plant, in the formation of its solid substance, and that the gaseous constituents contribute largely to the nourishment of the plant; consequently that neither water, nor the substance which it carries with it from the earth, alone supply the material from which plants are composed, as had generally been imagined." (Sachs.)

The vegetable Staticks "was the first comprehensive work that the world had seen which was devoted to the nutrition of plants and the movements of their sap, and while it noticed what had been already written on the subject, it was chiefly composed of the author's own investigations. An abundance of new experiments and observations, measurements and calculations combine to form a living picture of the whole subject." (Sachs — Balfour.) It attracted sufficient attention to be republished twice in English and was translated into French, German, and Italian.

Hales' experimental observations on Hæmostatics, or the "force of the blood" in animals, although for the most part made before those on vegetables, were not published until 1733. These observations have given him a recognized place in animal physiology.

JAN INGEN-HOUSZ

Ingen-Housz is gradually coming to be recognized as the effective founder of our knowledge of vegetable nutrition, though in this connection he shares honors with de Saussure, who published a quarter-century later when chemistry was more developed. The services of Ingen-Housz to physiological botany were first made generally known to the world through Sachs' *History of Botany*, published in 1875. Wiesner, his later (1905) biographer, thinks that Ingen-Housz is deserving of a higher place in the history of plant physiology than heretofore accorded to him. Wiesner made a very careful study of his life and works [7] based

[7] Jan Ingen-Housz, Sein Leben und Sein Wirken als Naturforscher und Artz. Wien, 1905.

on new sources and ranks him as one of the greatest investigators of the last half of the eighteenth century.

Jan Ingen-Hausz[8] (1730–1799) was of Dutch parentage, born in 1730, in Breda, Brabant. When, at the age of sixteen, he left the Latin school of Breda he was so accomplished in the classical languages that he was able to read Latin and Greek at sight, and could readily convert the text from one language into the other. His attainments and thorough knowledge of the subjects he had studied, were regarded as a sufficient preliminary training and he was allowed to begin the study of medicine. Thereafter, he had the advantage of an extended university training, pursuing scientific and medical studies from 1746 to 1757 in Louvain, Leyden, Paris, and Edinburgh. He received the degree of M.D. at Louvain in 1752, and in his subsequent post-graduate studies he broadened and deepened his knowledge of anatomy, chemistry, physics, and several phases of medical practice. He was especially interested in chemistry, and at the university of Leyden laid the foundation in this subject for his subsequent investigations of the chemistry of plant nutrition. At the age of twenty-seven he began the practice of medicine in his native city of Breda, and, in 1764, or 1765, settled in London where he had influential friends who had encouraged him to come to England. Here he planned his experiments on plant physiology, which were to become so famous, but before they

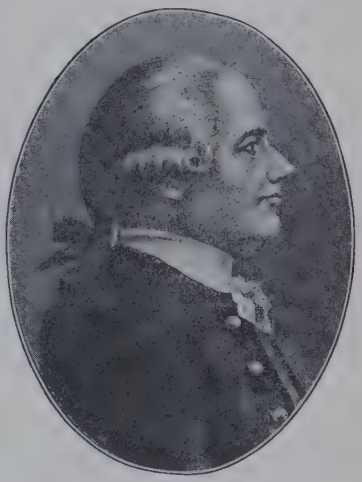

FIG. 125. — JAN INGEN-HOUSZ, 1730–1799. (*Acta horti Bergiani.*)

[8] Regarding the form of his name, — in his published works, authorized translations, and general correspondence, it appears as Ingen-Housz; in intimate letters to his wife he sometimes used the subscription, J. Housz. In Austria, and on bibliographic cards it is often spelled Ingenhousz; other variations are, Ingenhuss, Ingen-Houss and Ingenhus.

were carried out he accepted an invitation from the Court of Austria to become the personal physician of the royal family and went to Vienna in 1768.

Wiesner says that Ingen-Housz carried out his experiments chiefly at Vienna but the distractions of court life left him no time to put his results into form for publication; accordingly, in 1779, he returned to London, where he wrote his first notable work on plant physiology entitled *Experiments upon Vegetables, etc.*[9] This appeared in 1779 when he was forty-nine years of age. He was not one to rush into print with hastily made observations and conclusions; his first scientific publication had appeared when he was thirty-eight years old; his writings from the beginning show maturity and judgment. Ingen-Housz wrote his various works in English, Dutch, and French, not in German, although they were soon translated into that language.

He determined that the carbon, which constitutes such a large part of the substance of plants, comes from the carbonic-acid gas of the atmosphere. He discovered also that all vegetables give off carbonic-dioxide and that only their green parts give off oxygen in the sunlight and the bright daylight. When he wrote, in 1779, the "new" chemistry was in a formative stage and it was not possible to give a correct interpretation of his results, but within a few years the chemical composition of water and the mixture of two gases in the air had been determined, after which the significance of his results became clearer. In 1796, he published a second memoir[10] making use of the advances in chemistry, and at the same time stating what his observations had been seventeen years earlier. In the essay of 1796 he writes: "I discovered in the summer of 1779, that all vegetables incessantly alter the surrounding air changing a large part of it into carbonic-acid gas. . . . I found, that in roots,

[9] *Experiments upon Vegetables*, discovering their great power of purifying the common air in the sunshine, and of injuring it in the shade and at night. To which is joined, a new method of examining the accurate degree of salubrity of the atmosphere. By John Ingen-Housz. London, 1779. LXVIII, 302 (17) pp. with plate.

[10] *An Essay on the Food of Plants and the Renovation of Soils.* Forming an appendix to the report of the London Board of Agriculture for 1796.

flowers and fruits this change goes on in the presence of sunlight, but that only the green leaves and (green) sprouts suspend this process in sunshine and clear daylight." [11] Apparently he missed the liberation of carbonic-acid gas, as a concurrent process, by the green parts in the presence of sunlight, although Sachs thinks that he perceived this, since it is implied in what he says about respiration. At any rate, various statements of Ingen-Housz indicate that he understood that plants respire oxygen at all times as animals do. "Plants cannot live without respirable air" — that is, they require oxygen. "A plant which germinates in a vacuum dies quickly, and dies in all kinds of gases in which animals cannot live — as for example, carbonic-acid gas, nitrogen," etc. Ingen-Housz laid the foundations of plant nutrition and plant respiration in so far as they could be established in the state of chemical knowledge of his time. It was reserved for de Saussure who wrote later, not only to confirm his results but to add the significant point that the nitrogen constituent of plants comes from the soil, in the form of nitrogen salts and not from the air.

This being an important era in the history of plant nutrition, the work of Priestley and Senebier should not go entirely unmentioned. Priestley discovered (or, more properly, rediscovered) oxygen [12] in 1774, and made a number of observations regarding its properties and its behavior. Somewhat earlier than Ingen-Housz, he had determined that occasionally oxygen is liberated from plants, but Ingen-Housz went further and showed the conditions under which this takes place, so that we can disregard Priestley as a genuine contributor to the subject of plant physiology. Ingen-Housz was the man of the period who carried observations on plant physiology to their highest point and whose results were passed on to later generations.

[11] The English publication not being accessible, I have translated from the German as cited by Wiesner.

[12] The discovery of oxygen threw a new light on all physiology, and gave an impetus to chemistry which was rapidly advanced by the brilliant work of Lavoisier. Priestley held to the theory of phlogiston as the combustible substance, while Lavoisier showed that combustion was a process of oxidation, and thus liberated chemistry from one of the hindrances to its advance.

SENEBIER

Jean Senebier (1742–1809), however, stands in a somewhat different position. He was a Swiss pastor and sometime librarian of Geneva, who "made protracted researches into the influence of light on vegetation (1782–1788), and founded on their results a theory of nutrition, which he published in 1800, in a tediously prolix work in five volumes entitled *Physiologie Végétale*. In this work some valuable matter was concealed in a host of unimportant details and tiresome display of rhetoric, which for the most part are beside the question. But it must be acknowledged that Senebier was better provided with chemical knowledge than Ingen-Housz, and that he brought together all the scattered facts that the chemical literature of the day offered, in order to obtain a more complete representation of the processes of nutrition."

DE SAUSSURE

"The tedious prolixity of Senebier's book was one reason why it never enjoyed the measure of appreciation and influence which it deserved; but it was also thrown into the shade by the appearance of a work of superior excellence, distinguished at once by the importance of its contents, by condensation of style, and by perspicuity of thought. This work was the *Recherches Chimiques sur la Végétation* of Théodore de Saussure (1804), which contained new observations and new results, and what was still more important, a new method. De Saussure adopted for the most part the quantitative mode of dealing with questions of nutrition; and as the questions which he put were thus rendered more definite, and his experiments were conducted in a most masterly manner, he succeeded in obtaining definite answers. . . . The directness and brevity with which precise quantitative results are expressed, the close reasoning and transparent clearness of thought, impart to the reader of de Saussure's works a feeling of confidence and security such as he receives from scarcely any other writer on these subjects from the time of Hales to our own." [18]

[18] Sachs' *History of Botany*.

A word as to de Saussure's education and personal characteristics will be in order. (Nicolas) Théodore de Saussure was born at Geneva in 1767, son of the famous Alpine explorer; he began at the age of twenty to assist his father in field observations on the Alps and imbibed high standards of accuracy together with a wide acquaintance of external nature. His father, professor of philosophy in Geneva, was deeply interested in botany and had a good working knowledge of physics, chemistry, and geology. The son, already with a natural inclination towards chemistry and botany was now trained in rigorous scientific methods. He was by inclination a student and showed preference for a secluded life in the country where he was free from the distractions of city life. Although often spoken of as a recluse, he did not separate himself entirely from interest in public matters, and in the years 1814, 1824, and 1845, he was a member of the representative council of the Republic of Geneva. In 1841 he was elected president of the scientific conference then meeting at Lyons and showed great ability as a speaker. He died at Geneva in 1845 at the age of seventy-eight.

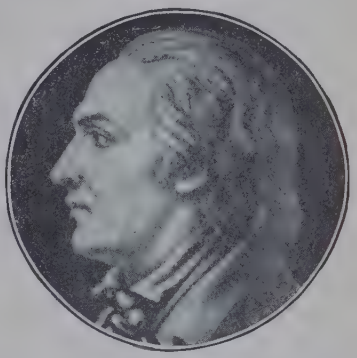

FIG. 126. — THÉODORE DE SAUSSURE, 1767–1845. (Picture loaned by J. Christian Bay, Chicago.)

In the preface to the *Recherches chimiques* we get a brief statement of de Saussure's aims and claims: "The researches with which I am occupied in this work have for their aim the influence upon vegetables of water, air, and the nutriment of the earth (terreau). . . . I attack questions which can be decided by experiment and abandon those which give rise only to conjectures. . . . The subjects which I have investigated especially are the functions of water and gas in the nutrition of vegetables and the changes which plants produce in the atmosphere. The observations of Priestley, Senebier, and Ingen-Housz, opened the

path which I have followed but they did not reach the goal which I have set for myself." They indulged in conjectures. "I have employed in my eudiometric proofs, sometimes acid potassium sulphate (l'hydrosulfure de potasse) and at other times phosphorus. These methods have enabled me to put into my analysis a precision which the authors who have preceded me were not able to attain by their use of nitrogen gas in the eudiometer. My researches have enabled me to show how much more water and air contribute to the formation of the dry substance of plants growing in a fertile soil, than even the materials which they absorb in watery solution through their roots." De Saussure also made new observations on the composition and quantity of ash remaining after plants had been burned. He concluded that in the normal nutrition of plants certain substances, such as calcium, phosphorus, silica, etc., are indispensable for normal growth — although occurring in very small quantities in the ashes. The preface closes with this remark: — "The route which I have set for myself is doubtless arid and fatiguing, but if one considers that the end towards which it is directed is the improvement of agriculture, one will bear with its difficulties and excuse its defects." [14]

The book gives so concisely the details of carefully made observations and experiments that it is not possible to give an adequate idea of its contents by a brief categorical review. He adheres closely to observations and experiments with only few remarks of a general nature. De Saussure was more precise and added to the observations of Ingen-Housz; he showed that water is fixed in the internal tissues of plants along with the carbonic-acid gas; he improved the knowledge of plant respiration and showed that the nitrogen constituent enters the plant through the roots. He introduced the quantitative method of measurement in determining the income, the outgo, and the permanent acquisitions of plants. He measured the intake and the release of gases, water, and solid constituents and struck a balance

[14] All quotations translated from the preface of the *Recherches Chimiques*, 1804.

to show what was retained by the plant and converted into vegetable substance. Although additions were made on certain details (Dutrochet and others), the subject of vegetable nutrition remained substantially where de Saussure left it up to 1840.

KNIGHT

While progress in the knowledge of vegetable nutrition was held in check for more than thirty years, an advance in another direction followed closely upon the work of de Saussure. Andrew Knight (1758–1838), an English horticulturist, made experiments on the direction of growth of stem and root of plants under changed conditions. It was a matter of common observation that under normal conditions, the stem grows vertically upwards and the primary root downwards — opposite reactions to the stimulus of the force of gravitation.[15] By growing plants on a revolving disc he contrived to change the direction of the stimulus acting on plants and produced changes in the direction of growth. On a rapidly revolving vertical disc, the roots grew in the direction of the centrifugal force and the stem in the opposite direction. These experiments of Knight, which were published in 1806, have become classical and are often repeated. He also made observations on the direction of growth of twining tendrils (1812) showing that in the Virginia Creeper the tendrils grow away from the light (negative response) while in many other plants they respond positively to the light and grow towards it. Thus was opened the fascinating subject of tropisms which of late years has been extensively investigated in both plants and animals.

SACHS

With the very notable work of Julius Sachs (later von Sachs), (1832–1897), the physiology of plants began to be advanced in various phases and to take form as an independent subject of study. When, in 1857, he announced himself as a Privatdozent in plant physiology at the University of Prague (where he was

[15] A reaction which we now call geotropism.

graduated in 1856), there was no recognized science of plant physiology; it was remarked by one of his colleagues "without great exaggeration" that two lectures would be sufficient to cover all that was known of the subject. After holding teaching positions in several schools, he went as professor of botany to the university of Würzburg where he remained to the end of his life, declining invitations from other important German universities. At Würzburg he made the department of physiological botany famous and attracted students from Germany and other countries to seek to work under his direction. He made a careful selection of the more talented and earnest applicants, admitting into his laboratory only ten at one time to work on problems of investigation. A ready and facile lecturer, he inspired students with enthusiasm, and his great influence was carried over even to the present generation of plant physiologists through men who were trained in his laboratory. Among the eminent plant physiologists who were trained under Sachs were Gœbel, Pfeffer, Vines, as well as many others. By teaching the facts and principles of plant physiology — many of which had been cleared up by his own searching investigations — he became the founder of the modern school of plant physiology.

FIG. 127. — JULIUS VON SACHS, 1832–1897. (From a photograph.)

Sachs was one of the first to insist on the continuity of protoplasm throughout the plant organism — a fundamental concep-

tion for investigations in physiology. By rigid laboratory methods he advanced the physiology of nutrition, investigating by micro-chemical methods the assimilation of substances within the internal tissues; he made extensive studies on starch-formation within the chlorophyll granules as well as of the absorption of starch and its conveyance to storage-tissues. He studied the conditions of growth and development including the reactions of plants to various forms of stimuli — to light and, especially, to the ultra-violet rays of light. He devised self-registering apparatus for recording the rate of growth, and apparatus for recording other physiological activities. He introduced the "Lithium-method" for determining the rate at which water and chemical salts travel up the stem.

As teacher, investigator, writer of textbooks, and trainer of investigators, he exerted as wide an influence on botany as any man of his century. His numerous technical contributions cover a wide range of topics, but, in our brief survey of the growth of biology, it is not necessary to make mention of them even by name. Besides the investigations referred to, he published four important textbooks: *The Handbook of Experimental Physiology of Plants* (1865); his great comprehensive *Textbook of Botany* (1868); his *Lectures on Plant Physiology* (1882); and his *History of Botany from 1530 to 1860* (1875) to which we have so frequently referred in this chapter.

With the advent of Sachs we arrive at the time of the establishment of vegetable physiology as an independent branch of investigation. From this time on the whole development of botany becomes very technical and its interpretation should be left to professional botanists.

SEXUALITY OF PLANTS

Before leaving the subject of vegetable physiology, however, we should have a brief review of the work that led to the recognition of the sexuality of plants. This subject, together with that of the method of fertilization and origin of the plant embryo, has occupied a prominent place in the history of botany. From

the last part of the seventeenth to the middle of the nineteenth century, the botanical literature abounds with comments on the sexuality of plants. The writings are of varied worth; some are mere conjectures, others with little or no observation, but, happily, there exist also some writings of scientific value supported by observation and experiments. The sexuality of plants is a physiological phenomenon, and as previously remarked is founded on structural features. For the classification of plants, Linnæus made use of the number, mode of insertion, and union of stamens, and certain structural features of the pistil, but he did nothing for the question of the phenomenon of sex and fertilization. The observers of especial importance who determined by experimental methods the genuine sexuality of plants were Camerarius (1665–1721), Koelreuter (1733–1806), and Sprengel (1750–1816).

Fig. 128. — Rudolph Jakob Camerarius, 1665–1721.

CAMERARIUS

Rudolph Jakob Camerarius was born at Tübingen in 1665; after completing studies in philosophy and medicine he traveled in England, France, Germany, The Netherlands, and Italy; at the age of thirty-three he became adjunct professor and director of the botanical garden at Tübingen. In 1691 and 1694 he published his extraordinary researches on the sexuality of plants, and in 1695 he attained the full professor's rank in succession to his father. He demonstrated (1691–1694) that the substance carried by pollen is indispensable for the production of seeds capable of germination. Previously Grew and some others had likened the pollen granules to the male element, but Camerarius went further; by prolonged observations and repeated experi-

ments he showed that the coöperation of pollen is absolutely necessary for the production of perfect seeds. This point amounts to the demonstration that in plants, as in animals, there is the egg and the fertilizing agent, and that fertilization is indispensable for formation of an embryo. His principal contribution on the subject is a small brochure entitled *De Sexu plantarum* [16] which was addressed in the form of a letter to Valentin, the professor of botany at Giessen. "The whole tone to the letter shows that Camerarius was deeply impressed with the extraordinary importance of the question, and that he was concerned to establish by every possible means the existence of sexuality in plants." Sachs says that "it contains more profound observations than were made by any other botanist before Koelreuter."

FIG. 129. — JOSEPH GOTTLIEB KOELREUTER, 1733–1806. (*Acta horti Bergiani.*)

KOELREUTER

Joseph Gottlieb Koelreuter, for years professor of natural history at Carlsruhe, stands forth as the effective investigator of sexuality of plants and cross-fertilization. He exhibited a modern spirit and produced work which Sachs says "seems to belong to our time." He made his first experiment in cross-fertilization in 1760, at Sulz on the Neckar, the place of his birth, and in 1761 published a preliminary account of his results which was followed by three other parts in 1763, 1764, and 1766.[17]

[16] Translated into German, *Ueber das Geschlecht der Pflanzen*, and made easily accessible in Ostwald's Die Klassiker der Exakten Wissenschaften, No. 105, Leipsig, 1899.

[17] Vorläufige Nachricht von einigen das Geschlecht der Pflanzen betreffenden Versuchen und Beobachtungen, Nebst Fortsetzungen (1761–1766). In Ostwald's Klassiker, 1893, with comments by Pfeffer; 263 pages.

His work is characterized by strict scientific methods, well-planned experiments, accurate observations, and great lucidity of exposition.

His work of greatest importance was the production of hybrid plants with seeds capable of germination. By dusting the pollen of Nicotiana paniculata (one of the ornamental tobaccos) on the stigmas of another species of the same genus he obtained his first fertile hybrids; and by similar methods he afterwards produced a large number of hybrids in different plants. Koelreuter's were the first truly scientific experiments on hybridization, and in 1853 Nägeli to a large extent based his general conclusions about hybrids on Koelreuter's results. Koelreuter also investigated the relation of insects to the pollenation of plants and made clear the general features of the process.

SPRENGEL

It remained for Konrad Sprengel, an investigator of remarkable sagacity, to bring forward observations that served to strengthen and make clearer the significance of Koelreuter's extraordinary results. He showed that cross-fertilization is the rule in vegetables, pointing out that in many plants the stamens and carpels come to maturity at different times and thus favor a fertilization from different plants. He missed the point afterwards made by H. F. Gärtner (1840) that cross-pollenization results in a larger number and greater vigor of seeds.

He very much extended the knowledge of the part played by insects in cross-pollenation, showing the existence of special contrivances whereby insects are attracted to flowers, and of structural adaptations whereby the nectar is conserved in a pure state for the use of insects. The fact that in many cases the perpetuation of plants depends on the coöperation of two classes of living creatures was thus brought into relief. This aspect of the matter was given new meaning by Charles Darwin in his many investigations on the fertilization of plants — investigations that in a certain sense form an appendix to Sprengel's work.

With the experimental demonstration of the existence of

sexuality among plants, the question of the method of fertilization arose, but the microscope was not sufficiently perfected in Koelreuter's time to enable him to detect its essential features. He supposed that some fluid part of the pollen found its way down the interior of the style to the ovary and fertilized the egg. The pollen tube was not described until 1823, by Amici; this was an important step in determining the actual process of fertilization in seed plants but for some years its significance was grossly misunderstood. Schleiden, disregarding the egg which is the part to be fertilized, maintained that the tip of the pollen-tube developed into the embryo. The rise and temporary dominance of Schleiden's pollen-tube theory was a feature of the time. The observations of von Mohl, Nägeli, and Hofmeister (cf. the next chapter) made it untenable, and the pollen-tube theory for which Schleiden vigorously contended went into the limbo of almost forgotten doctrines.

The sexuality of phanerogams and the essential features of their fertilization having been established, the corresponding phenomena were worked out for cryptogams by Hofmeister, De Bary, and others.

SUMMARY

This long chapter on the progress of botany from Linnæus to Schleiden has taken us over an important period for the growth of biology. During this interval the aims of botany were conceived in a new spirit. Linnæus had announced that the primary aim of botany was to classify plants — the rank of any botanist to be determined by the number of plants he might be able to name. This view which held in check the development of scientific botany, was discarded by the better investigators, and botany entered the period of liberation from the dominance of mere classification of plants. Besides the more scientific study of classification itself, investigators worked towards a knowledge of the intimate structure of plants and of vegetable physiology. Concurrent progress in these different lines is confusing if treated as a whole, and for clearness it be-

comes necessary to separate the advance under three sub-heads: (1) The progress in reference to classification; (2) knowledge of the inner structure of plants; (3) progress in vegetable physiology.

In the first division of the subject we find Linnæus using the work of Cesalpino, Bauhin, and Jung. He is not yet freed from tradition, but with a freshness of treatment all his own we find him imparting new life to old ideas. With his remarkable powers of reducing statements to terse formulæ he helped clear the science from a mass of verbiage. His greatest service was in establishing the binomial nomenclature which is used today in botany and zoölogy. He introduced order and system into classification and fixed the attention of naturalists on species. After him the de Jussieus and the de Candolles improved classification and, for the period under consideration, Robert Brown brought this aspect of botany to its highest development.

In the second division we find men of penetrating insight devoting themselves to investigations of a different type. By the use of the microscope, von Mohl and Nägeli in particular investigated the inner structure of plants and produced results of the highest importance. This work, so different from that of Linnæus, opened numerous questions of general biology. Through their researches and those of contemporaries arose the cell-theory, the protoplasm doctrine, the questions of fertilization, formation of the embryo, and a host of others that would never have arisen from the systemizations of Linnæus and his school.

In the third division, we have work beginning with the notable investigations of Stephen Hales on vegetable physiology (1727) and following in brilliant succession the researches of Ingen-Housz, de Saussure and von Sachs. The last established vegetable physiology in universities as an independent department of science.

As a physiological topic the question of sexuality of plants came under consideration, introducing the names of Camerarius, Koelreuter and Sprengel. The sexuality of plants was demon-

strated by Camerarius; this was reaffirmed by Koelreuter and supported by new observations. He also began the hybridization of plants, which subject was advanced by Konrad Sprengel and after the middle of the nineteenth century taken up by Nägeli, Charles Darwin, and Mendel.

CHAPTER XIX

THE PERIOD OF HOFMEISTER

With a Digression on Textbooks and Improvements in University Teaching

In this chapter we arrive at a turning-point in the history of botany. Between 1842 and 1860, the influence of two men of very different type resulted in enlivening the study of botany and imparting to it a new direction. The earlier impulse was, owing to improvements in university teaching of the subject, based largely on the principles laid down by Schleiden in a unique and original textbook of botany. In Schleiden's exposition of botany as an inductive science, the aims and purposes were placed in a new light, and the results of the most recent investigations were made a part of the instruction. This reform in teaching the subject was soon followed by the extraordinary discoveries of Hofmeister which influenced botany to a greater degree than any previous researches. These two features of advance will now be considered separately.

IMPROVED TEXTBOOKS

The advancement of science depends so much on the training of investigators and on a proper psychological approach to the subject, that it needs no argument to demonstrate that improvement of university teaching would exert a marked influence on progress. It is of prime importance to impart a feeling for the subject to young investigators and to set forth its aims as a subject of genuine scientific inquiry. The textbooks up to 1842 did not supply a worthy motive for the life-long pursuit of botany as a professional subject. For the most part they were patterned on the tradition of Linnæus. Progress of scientific botany was

impeded by attaching undue importance to the collecting and drying of plants and their classification. In the meantime the more vital aspects of the subject were neglected and the pursuit of botany became a spiritless task of assigning names to plants. The problems of structure, function, development, fertilization, life-histories, the relation of plants to one another and to their surroundings were too much neglected. Minds of superior type were not attracted to the subject.

A few men of great intellectual gifts, such as Robert Brown, von Mohl, Nägeli, and others, separated themselves from the Linnæan school and carried on fruitful investigations with plants from an entirely different standpoint. But the important results of these investigations were buried in proceedings of academic societies and had not yet been incorporated into textbooks of general botany. As Sachs remarks: "Such a condition of things is dangerous for every science; of what profit is it that single men of superior merit advance this or that part of the science when a connected view of the whole is wanting, and the beginner has no opportunity of studying the best things in their mutual relations."

Schleiden saw the imperative need of giving to botany another direction, and he produced a textbook, designated "Botany as an Inductive Science," which led young investigators into the new path. His true historical importance "is due not to what he did as an original investigator, but to the impulse he gave to investigation, to the aim and object which he set up for himself and others, and opposed in its greatness to the petty character of other textbooks."

Matthias Jacob Schleiden (1804–1881) received his first university training at Heidelberg; he was educated as a lawyer and engaged in practice at Hamburg — the city of his birth. His taste for natural science was so keen that, when he was twenty-seven years old, he deserted the practice of law, in which he had not been very successful, and went back to the universities to study medicine and botany. In this second period of his university life he attended Göttingen, Berlin, and Jena. He was

graduated from Jena, and, in 1839, was brought into the faculty of that university as adjunct (*extraordinarius*) professor of botany. Before his appointment at Jena he had published in-

FIG. 130. — MATTHIAS JACOB SCHLEIDEN, 1804–1881. Lithographed from a photograph.)

vestigations on the origin of plant-cells (1837) and had played his part in the formulation of the cell-theory. He remained at the university of Jena until 1862, having been advanced to the full rank of professor (*ordinarius*) in 1850. In 1863, he went for a short time to the University of Dorpat, in Russia, but soon

returned to Germany and settled in Dresden where he figured as a private teacher and a student in historical and philosophical lines. He did little by way of research in botany after 1850.

SCHLEIDEN'S TEXTBOOK

When Schleiden was thirty-eight years old, and after he had occupied his university position for three years, there appeared in 1842–1843, the first edition of his textbook of botany. Between 1843 and 1849 this treatise was published in two other much improved editions. Its German title, *Grundzüge der Wissenschaftlichen Botanik,* is commonly translated by English-speaking botanists as Schleiden's "Outlines" or as his "Principles" of scientific botany. Its secondary title, *Die Botanik als Inductive Wissenschaft* more graphically indicates its aims.

An outline of the main divisions of Schleiden's text will give an idea of its scope as well as an indication of its wide departure from the topics treated in the conventional textbooks of the Linnæan type. It is divided into four books with main titles as follows: (I) Chemistry of Plants, both the organic and the inorganic elements; (II) The Plant-cell regarded as an individual, of cells in combination, and the life of the plant-cell; (III) Morphology, general and special, — this is the chief part of the text occupying more than half the bulk of the entire volume; (IV) Organology, general and special.

If a textbook of science might be called exciting, this would apply to Schleiden's text. It was stimulating from its fresh point of view and from its extravagances of statement. It is a combination of new and exact observations interspersed with lively reflections on the matters under discussion and often with "coarse polemic of praise and blame of others."

Sachs says of Schleiden's treatise: "The difference between this and all previous textbooks is the difference between day and night; in the one, an indolent carelessness and an absence of ideas; in the other, a fulness of life and thought, calculated to influence young minds all the more, because it was in many respects incomplete and still in a state of fermentation" — etc.

Sachs' statement seems a little high colored, but at any rate it represents the estimate placed on the influence of this book by one who later produced the best textbook of botany of the nineteenth century. It was accorded high rank by many others, and by Anton de Bary, one of the most accomplished botanists of the time, Schleiden was dignified with the title "Reformer of Botany."

When Schleiden wrote about the state of botany and the work of his predecessors he was frequently one-sided, inaccurate, and inconsistent. In the fourth book on Organology, he says:

"If we consider the attempts that have hitherto been made to subject the life of the plant to scientific observation, we shall find that all those who have conducted them have brought to their works groundless prejudices, and, following the old beaten track, have not even paused to inquire whether or not it were right, and whether or not their prejudices were just; and they have even taken these latter as leading maxims to form the basis of all their investigations. I have already discussed the fanciful analogy between the physiology of animals and of plants. In consequence of the use of this absurd analogy, almost all the works that have hitherto appeared on vegetable physiology are perfectly worthless, for in no instance have they adopted the only true fundamental position, namely, the essential peculiarity of vegetable life; nay, the larger number of writers have not even given a comprehensive view of the facts already known, as such would have destroyed their assumed principles. . . . For want of such a plan little or nothing has hitherto been done. It is hence a consequence that all foregoing physiological experiments, and their results, are and must be worthless, because they fail in fundamental maxims and correct methods of research, and in the smallest as well as in the greatest matter it will be necessary for us to recommence our investigations." In this there is not a hint of the fine work of Hales, Ingen-Housz, de Saussure and Knight, who had equally high ideals and did work of a quality as good as Schleiden's best. He has occasion to mention these men in different parts of his text, but examples of

his supercilious tone as given above are frequent. He writes: "A knowledge of the functions and structure of the epidermal tissues depends upon accurate observations, which the author of this work was almost the only one to make during the present century" (!) (P. 71). . . . "Almost all the works that have hitherto appeared on the lower fungi are wholly useless, and may, without further consideration be cast aside." (P. 153.) In light of the complete overthrow of Schleiden's observations and conclusions about the origin of the embryo of phanerogams, it is rather amusing to read his statement on page 416 of the English translation. After giving a brief historical survey of the work supporting the idea "that the pollen-tube descended through the style into the seed-bud and became the embryo," he speaks of the imperfection of the observations already made and adds, "Thus the matter stood until I brought the matter to a conclusion by my researches."

Sometimes Schleiden expresses admiration for the work of a predecessor or a contemporary, and in this connection, his recognition of the importance of the English botanist, Robert Brown, in the rise of the new botany is interesting. "I am thoroughly convinced," he says in the German Introduction, "that future generations will designate Robert Brown as the particular shining Genius of botany who inaugurated this new epoch. In the mind of this original Spirit all the various parts of botanical science were gathered into a harmonious whole; with him all the various lines of testimony came to a single point, he was the first to be clearly conscious of their relative importance and their essential unity, through him the accumulated knowledge of plant organisms came to a living organically connected science, the object of which is a discerning insight into the related development of plant-life in all phases of its existence." (P. 3.)

Schleiden's pet annoyance was the botany of mere species-making; of this he remarks: "Most people of the world, even the most enlightened, are still in the habit of regarding the botanist as a dealer in barbarous Latin names, as a man who gathers flowers, names them, dries them, and wraps them in

paper, and all of whose wisdom consists in determining and classifying this hay which he has collected with such great pains."

But there is a brighter side to his writings; he based his book very largely on his own observations, and he gives excellent sketches of the microscopic structure of plants drawn from nature. He had correct ideas of the object of scientific inquiry and of the methods to be used in the pursuit of it. His treatise opens with an Introduction of one hundred fifty-eight pages chiefly on the principles of scientific induction and their use in the study of botany. In his general text he is very insistent on the necessity of investigating the stages of development of plants in order to understand their anatomy and physiology. In this he did a great service to biological science by making embryology one of the essential lines of inquiry.

The opening sentence, introducing his treatment of special morphology, is: "The history of development forms the groundwork for all special botanical morphology, and we must, therefore, have reference to it in choosing our general modes of classification." And his closing sentence to the same section, some three hundred fifteen pages later, is: "I will once more express my *Ceterum censeo:* There can be no science of Botany without the Study of Development." (P. 453.)

Taken as a whole the influence of Schleiden's book was very great, it placed botany on the footing of a natural science and made a turning-point in the progress of botany. The book was published in English translation in 1849, with the omission of the philosophical Introduction. The translation was made by Edwin Lankester from the second German edition, but an appendix contained the additions to the third German edition.

Schleiden's "Outlines" was superseded by Sachs' *Textbook of Botany* first published in 1868, and in several improved editions in subsequent years. This was a great improvement over Schleiden's text, embracing a more comprehensive treatment of morphology, with the path-finding researches of Hofmeister — of which we are soon to speak. It brought the student face

to face with the current condition of botanical investigation, and, as might be expected from the creator of the physiological botany of the nineteenth century, contained a fine treatment of the physiology of plants. There was also a chapter on the Origin of Species and the Theory of Descent — great additions to knowledge since the time of Schleiden.

This book was translated into English in 1875, and had great influence in England and the United States, as well as in Europe. The writer vividly recalls the stimulating effect produced by Sachs' textbook on himself and fellow students at the University of Michigan in the eighties of the ninteenth century.

While Schleiden's "Outlines" was stimulating investigations in botany, improved textbooks were published in other departments of biological science. These were by no means owing to the acceptance of Schleiden's text as a model, but were original ventures as a general expression of the times. Biological science was then in a flux and these texts mark a general turning towards better instruction in natural science in the universities, the historical importance of which must not be overlooked. As a pioneer among such treatises must be mentioned the monumental treatise on human and comparative physiology by Johannes Müller, appearing first in 1833, nine years before Schleiden's "Outlines." In zoölogy, the *Manual of Comparative Anatomy* of Stannius and Von Siebold (1845–1848), marks the upward trend. In 1852, Kölliker published his first text on Histology and Embryology. These various treatises coincided in a general way with the revival and progress of microscopical study of living organisms — a line of investigation which resulted in rapid extensions of biological knowledge and in clearing up many obscure relationships among living organisms.

HOFMEISTER

Of all the great men of botany of the nineteenth century the career of Wilhelm Hofmeister was the most phenomenal. Without a university training, without the help of a teacher in research, he lifted himself into recognition as one of the foremost

men of science of his time. Without previous university connections, he was advanced by a single step from the status of a tradesman to that of a professor of full rank in the university of Heidelberg — the oldest university of Germany. This was a tribute to the extraordinary attainments of the man.

While Schleiden owes his permanent place in botanical history to his textbook, Hofmeister owes his to technical investigations and to the masterly way in which he combined these investigations into an orderly whole and interpreted their meaning. Hofmeister's work was of a higher type and exerted a more lasting influence on progress.

In view of his great eminence, it is difficult to account for the scarcity of biographical sketches and "Appreciations" of Hofmeister. At the time of his death, in 1877, the scientific periodicals contained only brief notices on his life, and botanists of today have had difficulty in finding a satisfying sketch of Hofmeister and his labors written by one of their own craft.[1]

Since he attained such eminence the facts about his education, his worldly circumstances, his advantages and limitations of environment, the conditions under which he did his work, etc., acquire an especial interest. Hofmeister was essentially a self-made man; no especially favorable circumstances were responsible for his advancement; he was not the product of his environment but of his heredity. He was gifted with a penetrating mind, he showed great capacity for work, fixedness of purpose, and, apparently reached many of his conclusions by the "intuition of genius." One circumstance that doubtless favored his output was the love and congeniality in his home-life.

In the account of his life which follows I have drawn largely on the narrative of Pfister, who obtained many of his facts from the Hofmeister family.

[1] A sketch of Hofmeister, with portrait, was published in *The Plant World*, 1905. This was a translation from the German of Professor Göbel by Professor Francis E. Lloyd. The most comprehensive memoir on Hofmeister and his scientific work is by Ernst Pfister in *Heidelberger Professoren aus dem 19 Jahrhundert*, Vol. 2, pp. 267–378. For a portrait different from that in *The Plant World*, see *Acta horti Bergiani*, Vol. 3.

Wilhelm Friedrich Benedikt Hofmeister was born in 1824, at Leipzig, where his father was a highly respected bookseller and occasional publisher. He inherited from his father an interest in botany, and from his mother a keen mind. His earliest instruction outside the home was in a private school, from which he entered the newly-founded *Realschule* of Leipzig. This institution had been established in 1834, by Dr. Karl Vogel, a friend of the elder Hofmeister. Vogel was a competent teacher, with fresh ideas of education, and emphasized a kind of mental training that led students to think for themselves. In 1839, at the age of fifteen, Wilhelm Hofmeister left the *Realschule* and ended his education under the direction of masters. His further attainments were the result of self-education, but it must be remembered that he was especially acquisitive and original. He immediately reviewed the principal subjects he had pursued at the *Realschule* (physics, chemistry, algebra, trigonometry, geography, etc.) and added to them. He lacked the much valued classical training of the German Gymnasia, but the powers of his mind had been improved by methodical training in those subjects which he had pursued at Vogel's *Realschule*. Having a natural taste for music he learned to play the violin without a teacher and he began to take an active interest in the study of plants and insects, stimulated thereto by his father and some of his learned friends.

In the summer of 1839, just after leaving the *Realschule*, he entered the musical establishment of Cranz at Hamburg as "Volentar" — an apprentice or unsalaried clerk. This has given rise to the statement in some cyclopædias (*Britannica*, etc.) that he was by occupation a music dealer — this connection, however, was only a temporary venture engaged in between the ages of fifteen and seventeen. From the age of seventeen, for twenty-two years (1841–1863) he was in his father's bookselling establishment at Leipzig. The article in the *New International Cyclopædia* says he was a "druggist" but of this I find no authentic record. At Hamburg, his mornings were relatively free and he employed his time in a review of his previous studies, in taking

lessons on the violin and in excursions on foot and by boat in the vicinity of Hamburg.

In 1840, Hofmeister's father acquired a property at Reudnitz in the suburbs of Leipzig, comprising a house and a garden in which he arranged plants according to the natural system. At first the house was used as a summer residence, but was soon converted into a family dwelling occupied by the parents, their children with their families, and for some time four families of Hofmeisters lived happily and in harmony on this parental domain. Here Wilhelm Hofmeister brought his wife in 1847; here were born five of his children, and here he carried on his investigations and prepared his monumental publications. In 1841, he entered his father's firm as foreign correspondent and was connected with the business until his call to the university of Heidelberg, in 1863. When he entered his father's printing-house, he at first had some leisure to devote to his studies; but very soon the business at the Leipzig store so occupied his time, that, as he himself said, his only regular working hours in science were from four to six o'clock in the morning. In the Hofmeister household, love, congeniality, simple living, and high thinking prevailed. The families living there had friendly social relations with a few kindred spirits of learning and culture, and all this was helpful to the development of Wilhelm Hofmeister. He had formed a friendship with Professor Reichenbach, of Hamburg, who encouraged him. He was also greatly influenced by Schleiden's "Outlines" which directed his attention to microscopic botany and to the embryology of plants. In this field of work his extreme nearsightedness was not a handicap but in some ways an advantage in the handling of minute objects and in making thin sections for the microscope. It speaks well for his sharp mental discrimination that, at this early age, he pronounced the work of von Mohl of higher quality than that of Schleiden.

In 1847, he published a scientific paper, the next year another one, and, in 1849, his first work of commanding importance, the treatise on the origin of the embryo of Phenerogams, was published as an independent brochure by his father. This work at-

tracted such wide attention in the scientific world as well as among botanists, that, in less than two years after its publication, the university of Rostock conferred upon him the degree of Doctor of Philosophy *honoris causa,* thereby extending the first formal recognition from the university world of his high standing as an investigator. The Royal Saxon Society of Science, at Leipzig, elected him to full membership.

He was now working with intense application, and in 1851, his father's firm published another independent work. This was his famous path-making treatise entitled "Comparative Researches on the Germination, Development, and Fruit-formation of the Higher Cryptogams and on the Seed-formation of the Conifers." This was the high-water mark of his achievements — a research so brilliant that it led von Sachs in his history of botany to exclaim: "The results of the investigations published in the *Vergleichende Untersuchungen* in 1849, and 1851, were magnificent beyond all that has been achieved before or since in the domain of descriptive botany; the merit of the many valuable particulars, shedding new light on the most diverse problems of the cell-theory and of morphology, was lost in the splendor of the total result, which the perspicuity of each separate description revealed to the reader before he came to the conclusion of the work, and there a few words in plain and simple style gave a summary of the whole." The significance for botanical science of these two works will be spoken of later. The treatise of 1849 was dedicated to Hugo von Mohl, that of 1851 to "*Seinem treuen Vater in Liebe und Dankbarkeit,*" which reminds one of the famous filial tribute of Pasteur in the dedication of one of his chief works to his father.

After 1851, as products of his great activity, researches along the same general line continued to appear, and his friends began to fear that he would break down under the strain of business cares and activity in research. Then came, in 1863, a signal recognition of his distinguished services to the progress of scientific botany; this was an invitation to accept the professorship of botany in the university of Heidelberg. It is to be remembered

that the practice and traditions of German universities were so conservative that, except in the Faculty of Medicine, it was unprecedented for a man without previous university connections to be called to a professorship. Hofmeister had never even attended a university, and from the age of fifteen to thirty-nine had been engaged in trade. These factors were against him, and it was purely on the basis of extraordinary merit that he was seriously considered for the position. Hofmeister was not nominated in the usual way by vote of the philosophical faculty; he owed his nomination to the Grand-Ducal Ministry of Baden. In 1854, Professor Reichenbach died at Heidelberg and the philosophical faculty named von Mohl as its choice to succeed him. Owing to circumstances, however, the call was not made, and in the interim the position was held by the adjunct professor, Anton Schmidt. In 1861, members of the faculty took a new vote and named de Bary as their choice, but this action did not result in a call. In May, 1863, the Grand Ducal Ministry said to the faculty if their vote of 1861 was not carried out, that the ministry would nominate Dr. Wilhelm Hofmeister for the position. They spoke of their candidate as follows: "He impresses us as one of the foremost botanists of Germany, as a man of genial disposition, of great technical skill, and active productivity, who for the first time shows an inclination to accept an academic position, and also at present has the certain prospect of a call to Hamburg." Notwithstanding some misgivings expressed by the faculty, he received this appointment, and, in the fall of 1863, moved with his family to Heidelberg, entering the university with full rank as Ordentlicher professor of botany and Director of the botanical garden.

From the accounts of Gœbel and Pfitzer, two of his botanical contemporaries, Hofmeister (Fig. 131) was a likable personality, alert, and interesting. "His appearance had in it nothing of the German type; he looked like a southern Frenchman. Of small supple form, he possessed a dark, clear-cut, and uncommonly vivacious face; he was always bubbling over with activity and ever showed great kindness to his students."

As a lecturer in the university, Hofmeister overestimated the state of preparation as well as the earnestness of general students of science, and placed his lectures on so high a plane that he emptied the benches of his lecture room of the miscellaneous students in pharmacy, pre-medical studies, and general science, but he held the attention and secured the admiration of the more advanced and serious-minded. Among the men who worked under him either at Heidelberg or at Tübingen, we find the names of Askenasy, Engelmann, Gœbel, J. Knauth, Krutitzky, Millardet, N. J. C. Müller, Pfitzer, Rosanoff, and Zacharias.

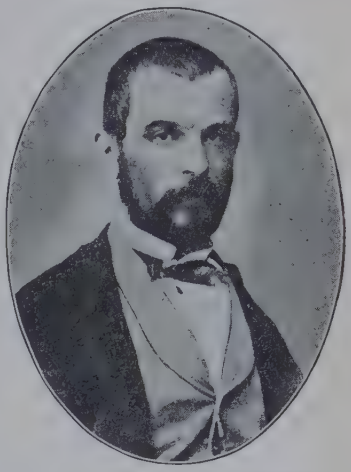

Fig. 131. — Wilhelm Hofmeister, 1824–1877. (From a photograph by E. Lang. *Acta horti Bergiani.*)

He was especially expert in laboratory instruction and made before his students microscopic preparations of remarkable fineness. With his colleagues on the faculty he showed himself a good companion, a ready and interesting talker of wide intelligence, and made many personal friends. Owing to a variety of small causes involving differences of opinion the faculty at Heidelberg became divided into two camps; Hofmeister had friends in both, and being too sincere to dissemble, his friendships became strained in some quarters, and his life there was made unhappy. He was further distressed by sickness in his family, and within a year suffered the grief of losing his wife and youngest daughter by tuberculosis. He was now (1872) called to Tübingen to succeed Hugo von Mohl, and gladly accepted this opportunity for change of environment. Having been at Heidelberg nine years, he was destined to hold the professorship at Tübingen for only four years, and thus ended his entire university career within thirteen years. His two

favorite sons, aged respectively twenty-three and twenty-five, died of tuberculosis, both in 1875.

In 1876 he himself suffered a stroke of apoplexy and was obliged to resign from his professorship; he passed away at Leipzig in 1877.

We come now to consider Hofmeister's scientific publications and their influence on botany. There is a marked unity of purpose in the rather numerous scientific memoirs of Hofmeister. They are not disconnected pieces of work, containing discoveries of miscellaneous facts, but for the most part they form a series of program-studies extending over a number of years, and directed towards the solution of definite problems.

In 1847, he began a series of publications which extended to 1860, on the origin of the embryo of the flowering plants, including fertilization of the egg and formation of the embryo. The first of these papers to attract wide attention was published in 1849, on the origin of the embryo in the Phanerogams. This paper with the German title *Die Entstehung des Embryo der Phanerogamen* occupies a central position in the series on the embryo of the Phanerogams. It is a famous botanical document, published as a separate work of eighty-nine quarto pages, and fourteen copper plates embracing no less than four hundred twenty-nine figures.

There is a characteristic directness about Hofmeister's style which requires close attention in reading. His writing is dignified, straightforward, and impresses one with the remarkable clearness and certainty of his observations. His brief critical remarks are in marked contrast with the boastful and exaggerated tone of Schleiden.

The work of 1849 starts abruptly with a description of observations and without any preliminary remarks. At the end there are nine pages of a clear and concise summary and conclusions, in which he shows that the thirty-eight plants of nineteen genera examined all agree in essential features as to their method of fertilization and embryo formation, and he expresses the belief that these phenomena are the same for all phanerogams. The

facts assembled in this paper undermined the pollen-tube theory of Schleiden, and in 1855 he published decisive researches which accomplished the complete overthrow of Schleiden's contention. About 1840, one of the questions that vexed the botanical world was the origin of the embryo in plants. Schleiden maintained that the embryo arose from the tip of the pollen-tube — thus making the embryo-sac a nidus within which the end of the pollen-tube was nourished into an embryo plantlet. Hofmeister showed that the pollen-tube carries elements of fertilization, and that the embryo is formed from an egg-cell already existing within the embryo-sac developed within the ovule. He traced the origin of this egg-cell showing that a substance carried by the pollen-tube fertilizes the egg, and how the embryo develops within the ovule out of this fertilized egg.

In these observations he had been in a way preceded by Amici and Robert Brown, but Hofmeister's observations were so extensive and exact that Schleiden's observations on these points and his theory of formation of the embryo were set aside. Hofmeister not only traced the origin of the egg within the ovule, but also showed the development, cell by cell, of the embryo.

The work published in 1849 on the embryo of the flowering plants was merely the starting-point of a larger enterprise. Already, before its publication, Hofmeister was engaged in similar investigation of the lower plants. Although some of the main facts in the life-history of ferns and mosses had been made known, the cryptogams had been quite generally neglected in botanical investigations. Ignorance of cryptogamic botany was, indeed, the chief cause for the long delay in discovering a unity of relationship throughout the vegetable kingdom. Hofmeister made his studies comprehensive, including the lower as well as the higher plants, and he erased the line of demarcation that was supposed to separate the cryptogams and the flowering plants.

From his comprehensive studies there resulted "that great general pronouncement" first published in 1851 — the most remarkable single piece of scientific investigation of the period —

a work which F. O. Balfour says " will always stand in the first rank of botanical books." Its long title, however, is not alluring: *Vergleichende Untersuchungen der Keimung, Entfaltung und Fruchtbildung höherer Kryptogamen und der Samenbildung der Coniferen.* A book of one hundred seventy-nine quarto pages and thirty-three copper plates, published in Leipzig by his father's firm. After its publication there followed a number of further researches along the same line, extending his observations to other plants and making clearer and fuller his conclusions. At the request of the Ray Society of London, he combined his various researches of this nature into a uniform whole, " revising the text throughout and adding a quantity of matter existing in manuscript." This assembled product appeared in English translation in 1862, under the title: *On the Germination, Development, and Fructification of the Higher Cryptogamia, and on the Fructification of the Coniferæ.* The original publication of 1851 is difficult to obtain, and I have been obliged to use only the readily accessible English translation. It is more extensive than the original of 1851, making a volume of four hundred ninety-one octavo pages of text, with seventy-five plates and more than eleven hundred figures.

By extensive observations Hofmeister demonstrated the existence of an alternation of a sexual with an asexual generation in all plants, from the lowest to the highest, which made necessary some sort of theory of their community of descent. These two points require some further elucidation.

The term " Alternation of Generations " had been introduced into biology by Steenstrup, in 1845, to apply to those cases in animals where a generation arises by budding from parent-forms which is very different in appearance from the parents, and this generation, in turn, gives rise by a sexual process to the parent-form. This is well illustrated in the hydroid polyps, where a colonial branching form sets free by budding medusoids, which as independent jelly-fish swim freely and lead an independent existence. This generation of medusoids produces eggs and fertilizing agents, and their offspring resemble the original parent

form but not at all the generation of beings from which they have sprung. The alternation of generations in plants is only generally similar to this process but it extends to them all. By the germination of the spores of ferns, for illustration, there arises a plant which produces the sexual elements, and from the union of these there develops a generation similar to the original plant. Furthermore, this phenomenon, although obscured in the higher forms by the production of seeds, is common to all plants. Says Goebel, in 1905, " This is, in very truth, the greatest discovery that has ever been made in the realm of plant morphology and taxonomy."

Another sweeping conclusion resulted from Hofmeister's " Comparative Researches "; they revealed all plants as genetically related; no longer could individual plants be looked upon as separate creations, or entities; the lower forms were shown, by their structure and method of development, to merge into the higher forms making a unified series. Thus, almost automatically, the conception of the community of descent of plants replaced the earlier view. This interesting fact is of historical importance in connection with the rise of the theory of organic evolution. In 1851, fully eight years before the publication of Charles Darwin's *Origin of Species,* a theory of community of descent of plants had been made necessary by the illuminating researches of Hofmeister. Darwin's publication made it general, and, after 1859, it applied to both animals and plants.

How directly Hofmeister arrived at his points is shown by his giving (in the English translation referred to) only eight pages of review and general conclusions, after four hundred thirty-three pages of scientific results. Hofmeister is not confused by the often perplexing conditions brought out by his researches on individual plants; with remarkable clearness he picks out the corresponding processes; he shows that a uniformity exists between the fruit-formation of mosses and the embryo-formation of higher cryptogams, and that the formation of the embryo of gymnosperms is intermediate between the higher cryptogams and phanerogams. In the cryptogams the fertilization is

accomplished by free swimming spermatozoa, in the conifers and angiosperms by a pollen-tube, within which non-motile nuclei effect the fertilization.

Here, by the phenomena of similarities in respect to fertilization, fruit-formation and embryo-formation, all plants from the lowest to the highest are united into an unbroken chain. Hofmeister says: " The phanerogams therefore form the upper terminal link of a series, the members of which are the Coniferæ and Cycadeæ, the Vascular Cryptogams, the Muscineæ, and the Characeæ. These members exhibit a continually more extensive and more independent vegetative existence in proportion to the gradually descending rank of the generation preceding impregnation, which generation is developed from reproductive cells cast off from the organism itself."

After going to the university of Heidelberg, Hofmeister published, in 1868, his *Allgemeine Morphologie,* introducing into morphology a new conception somewhat similar to the experimental morphology that in later years was extensively developed by zoölogists. But the idea of Hofmeister of the dependence of plant organization on inner and outer conditions, has, as Goebel suggests, been too little followed up by botanists.

He projected a handbook of plant physiology with the collaboration of de Bary, von Sachs, and several other botanists of high standing. Hofmeister was designated as editor, and although he supplied and published most of his share, the enterprise as a whole was never completed. In addition to the works mentioned he published an excellent treatise on *Lehre von Pflanzenzelle* and some observations on the physiology of plants. Out of his whole scientific product the publications of 1849 and 1851 stand forth in relief as the best known and as containing his most notable and fruitful work.

Hofmeister's discoveries and conclusions changed the outlook and entered largely into all future progress of botany. Besides his many individual contributions to the knowledge of plants he will be remembered for three outstanding generalizations:

(1) He demonstrated the true nature of fertilization in flower-

ing plants; observed the origin of the ovum and the formation of the embryo cell by cell. These results were published in 1849.

(2) In 1851 he published his observations on the fertilization and fruit-formation of higher cryptogams and the conifers, connecting these results by broad comparisons with his observations on the angiosperms. This publication embraced the discovery of alternation of generations throughout the vegetable kingdom.

(3) His comparative studies made necessary for all plants a theory of community of descent.

After Hofmeister we enter the modern era of plant study and, since no one except a professional botanist can adequately write the history of its more recent developments, this is a convenient point at which to leave the story of the growth of biology from the botanical side. There remain, however, to be considered in a later connection, certain advances of the nineteenth and twentieth centuries that are broadly biological. Such topics as the cell-theory — the result of the work of both botanists and zoölogists — and the rise of a separate division of biology, named Cytology, belong to this category. Also such general advances as the experimental study of heredity and discovery of the laws of inheritance. These experimental studies first (or at least very early) carried out by Mendel on plants, became the starting point, at the opening of the twentieth century, for active investigation of both botanists and zoölogists, and gave rise to the subject of Genetics. Furthermore, the work of Pasteur was so broadly biological in character, that in following it up, botanists and zoölogists were drawn into one circle of investigation. The doctrine of organic evolution, in which Hofmeister was a pioneer on the botanical side, is likewise a field where botanists and zoölogists met on common ground.

Before closing this chapter it may be worth while to recall some of the main features of botanical progress. Beginning with Theophrastus, the father of scientific botany, we pass through an early period of botanical illustration (Crateuas) to Dioscorides, with an indication of the great influence of his *Materia Medica,* both in manuscript and in printed editions. We see

botany cultivated by medical men and note the wide knowledge of plants possessed by Galen. In the Middle Ages, we see Albertus Magnus, although held back by the general state of knowledge of the time, striving to lift botany to a higher plane. After this we see the revival of botanical illustration by Brunfels and Fuchs, and the beginning of accurate descriptions of plants by Bock and Valerius Cordus. Then through Caesalpino, the Bauhins, Jung, and Ray to Linnæus — with the microscopic studies of Malpighi and Grew representing an early movement in another direction. The search for natural affinities of the earlier observers continued by the de Jussieus, the de Candolles, and Robert Brown. Many pieces of thorough scientific work, but the investigators were always hampered by belief in the constancy of species and lack of knowledge of the Cryptogams. Parallel with the advances just mentioned we see the physiological experiments of Hales, de Saussure, Ingen-Housz, and Knight, through to Sachs. In the nineteenth century microscopic studies into structure and development of plants introduce a new current running counter to that of the Linnæan school. Through the work of von Mohl, Nägeli, Schleiden, and Hofmeister botany was reformed and given a new outlook. And with the work of Hofmeister came the discovery of the common lineage of plants. His work led into a period of rapid advance in which de Bary, Sachs, Strasburger, Gœbel, and Pfeffer were great figures.

CHAPTER XX

PHYSIOLOGY FROM HARVEY TO CLAUDE BERNARD

The development of vegetable physiology and other physiological topics such as Harvey's demonstration of the circulation of the blood and his general influence on the growth of science have already been dealt with; [1] in this chapter we attempt only a brief outline of the rise of animal physiology. Of course, animal physiology had a parallel development with anatomy and other allied branches of natural science. In recent years it has grown into a subject of vast proportions, and a special treatise would be necessary to depict in any detail its rise and progress. As human physiology it has medical connections; as general physiology it is broadly biological and after Haller's time physiology occupies a prominent place in biological history. At least some parts of anatomy are basal to physiology. Anatomical studies reveal the architecture of living beings from the simplest one-celled organisms through those of intermediate grade up to the most complicated and highly developed, but they leave aside the question of the office of cells, tissues, and organs. On the other hand, the aim of physiology is to investigate all manner of vital manifestations and, if possible, to determine their nature. While modern physiology is based largely on physics and chemistry, it cannot get along without anatomy. The arrangement of cells, blood vessels, and nerves constitutes "physiological anatomy" and a knowledge of these purely structural features is indispensable to the physiologist. The physiology of Harvey and Malpighi was indeed almost wholly anatomical. Borelli in the last part of the seventeenth century [2] made a start in applying the discoveries

[1] Cf. Chapters X and XVIII.

[2] De motu animalium, 1680–1681.

of physics to physiology and nearly a hundred years later Spallanzani investigated the chemistry of digestion, but it was not until the discovery of oxygen in 1774 and the subsequent development of chemistry that chemical physiology made much advance.

PHYSIOLOGY OF THE ANCIENTS

Properly speaking, there was no science of physiology before Harvey, but a few words concerning the physiological ideas of antiquity and the physiological experiments of Galen will be in place. Ancient physiology was dominated by the conception of the *pneuma;* this was a very subtile hypothetical substance supposed to exist in the atmosphere which entered the body by respiration and was responsible for vital activities. In its early form the *pneuma-theory* was an attempt to explain vital manifestations on a materialistic platform, but in the Middle Ages vital activity came to be looked on as a mystical process originating in a sort of "vital force" which manifested itself only in living bodies. Thus a mystical supernatural force was introduced as a *deus ex machina* and here was started that contrast between the mechanistic and the vitalistic views that in some form or another has ever since prevailed in physiology.

GALEN

Galen (130–201) on account of his numerous physiological experiments is worthy of especial consideration. He was the first great experimenter in physiology — performing a larger number of experiments on animals than are ascribed to Harvey (*Cf.* Chapter V). He was at his best in pure experimentation but in matters of interpretation he leaned towards the mystical and supernatural. He was a firm believer of design in nature and sought a teleological explanation for vital manifestation rather than a natural one — with all his experiments he did not materially advance physiology. He still believed that blood in getting from one side to the other passed through minute pores in the

septum of the heart. As Garrison has said, he believed that the blood received " natural spirits " in the liver, " vital spirits " in the left ventricle of the heart and that the " vital spirits " are converted into " animal spirits " in the brain, the whole organism being animated by the *pneuma*.

HARVEY

The most obvious hindrance to the development of physiology between Galen and Harvey [3] was the lack of knowledge of the circulation of the blood. Until that fundamental conception was established there could be no science of physiology. William Harvey supplied this need; with his demonstration of the circulation (*Cf.* Chapter X) the whole conception of feeding of the tissues, of respiration, and of glandular secretion took on a new form. At one stroke he opened the path to progress, a path that had been concealed from Galen and from others before Harvey. The belief in the existence of pores in the septum of the heart had for a long time stood in the way of understanding how the blood gets from the right to the left ventricle. The anatomist Vesalius made record that he could not find these pores, and after investigating the question Harvey exclaims, " By Hercules, no such pores can be demonstrated, nor in fact do any such exist " (*Cf.* p. 204). Harvey's conclusions were based on anatomical structure, on his observations of the sequence of contraction of the auricle and ventricle in the heart of many animals, and on quantitative determinations of the blood flow.

[3] Between Galen and Harvey the most conspicious figure in suggesting reforms in physiology was Paracelsus (1493–1541), that eager restless spirit whose life and service have been so completely dealt with by Karl Sudhoff. " The most original medical thinker of his century " he was far in advance of his time; he tried to make chemistry apply to physiology at a time when chemistry was immature. His writings are suggestive and contain examples of prevision. He was the forerunner of Van Helmont who took up the doctrines of Paracelsus and besides this, as we have seen, made experiments in vegetable physiology. Sir Michael Foster points out that Van Helmont so handled the doctrines of Paracelsus that in a modified and developed shape they found lodgment " in ordinary medical teaching, and served as the starting-point of that chemical investigation of the problems of living beings which since that time and especially in these later years has been so fruitful of results."

Following Harvey came a number of interesting physiologic investigations, and in a fuller account than ours it would be necessary to treat of the work of Borelli, Malpighi, Van Helmont, Réaumur, and others. However interesting their investigations may be to the physiologist, as examples of early work, the straight path of progress brings us at once from Harvey to Haller.

PERIOD OF HALLER

The great service of Haller was to place physiology on the footing of an independent science. At the beginning of his period physiology had no separate existence; in the university curriculum it was united with medicine and anatomy. When Haller was fifty years of age he published the first comprehensive textbook in which the scattered facts were brought together and presented as a whole. The effect of this was to make physiology a subject to be pursued for its own sake, not merely as an adjunct to medicine.

Haller was a man of vast and varied learning. His early attainments in language and literature were phenomenal, and later he won recognition in anatomy, botany, embryology, and physiology. He was somewhat pompous and overbearing, and made such a display of his scholarship that by unsympathetic critics he was alluded to as "that abyss of learning." He was a contemporary of Linnæus, and so thoroughly acquainted with botany that Linnæus feared the criticism of Haller more than that of any other person.

Albrecht von Haller (von Haller after 1749) was born at Bern in 1708 of an ancient Swiss family. Severely trained in youth by private tutors, his education was continued at the Universities of Bern, Tübingen, and Leyden. Although his early training was chiefly in language and literature he showed aptitude for the investigation of nature, and presently he entered the University of Tübingen to pursue the medical sciences. After a short residence at Tübingen he went to Leyden, being attracted thither by the great fame of Boerhaave. He also had the good fortune to come under the anatomist Albinus, the younger.

After receiving the degree of Doctor of Medicine in 1727 he traveled in England, Belgium, France, and Switzerland, making the acquaintance of many men of science and learning, and indeed stopping at Basel long enough to study mathematics under

FIG. 132. — ALBRECHT VON HALLER, 1708–1777. (Frontispiece in his *Elementa*, 1758.)

John Bernouilli. In 1730 he began the practice of medicine in Bern but devoted much of his time to the study of anatomy, botany, and physiology. Through his researches and publications he attained recognition as a scientific man of marked promise and there was created for him a chair of anatomy, botany,

medicine, and surgery in the newly-founded university of Göttingen. He was invited to take this position by George II, King of England and Elector of Hanover. "Haller accepted the offer and here at Göttingen for seventeen years he labored making physiology the chief duty of the chair." He was recognized as a teacher and investigator of exceptional ability and declined tempting offers from the universities of Oxford, Berlin, and elsewhere. After seventeen years of extraordinary activity at Göttingen, much to the regret of the university authorities he decided to retire to his native city of Bern, where for twenty-three years longer he followed literary and scientific pursuits and where he died in 1777.

Haller produced a large amount of literary and scientific work but here we shall speak only of a part of his scientific work and especially of his textbook of physiology. He made notable observations on the embryology of the chick — the best between Wolff's and Pander's; he made researches on the mechanics of respiration and the formation of bone, but his most important physiological investigation was on the response of muscles to direct stimulation — a property which now we call contractibility but which he designated "irritability of muscles." While he was a good observer he was by no means so reliable as interpreter. He vigorously opposed the correct view of Wolff that development of the embryo is a process of gradual building, and maintained that the embryo is pre-formed within the egg and that its development consists in the expansion of the already formed miniature. As it turned out, also, his researches on the responses of muscle to stimulation formed a new basis for the development of an erroneous conception of vitality. For all of this, however, Haller is not to be blamed. As Verworn has pointed out Haller's own experiments upon the phenomena of "irritability" were exact and his own theory of vitality was moderate, but the whole matter was misunderstood by his followers and misinterpretations followed. In attempting to explain the meaning of the phenomena which he had observed there grew up the doctrine of the existence of a special vital force mani-

fested only in living organisms. In its full development this doctrine provided for a distinct duality between vital force and the tissues of the body — making all vital activities dependent on a mystical supernatural agency. This assumption removed vital phenomena from the domain of clear scientific analysis, and for a long time exercised a retarding influence upon the progress of physiology.

Haller's chief service of permanent value was that he brought into one work all the facts and chief theories of physiology carefully arranged and digested. This, as said before, made physiology an independent branch of science to be pursued for itself and not merely as an adjunct to the study of medicine. The work referred to is his Elements of Physiology (*Elementa physiologiæ corporis humani*); the first volume was printed in 1757 and the eighth and last volume in 1765. Sir Michael Foster says that this book marks an epoch in the history of physiology, "indicating the dividing line between modern physiology and all that went before."

As expositor of his science Haller takes high rank. Foster's statement of the character of this treatise cannot be improved upon: "When we open the pages of Haller's *Elementa* we feel that we have passed into modern times. Save for the strangeness of much of the nomenclature, and for no small deficiencies in all that relates to the chemical changes of the body, we seem to be reading a modern textbook, a modern textbook of the most laborious and exhaustive kind. Haller passes in review all the phenomena of the body. In dealing with each division of physiology he carefully describes the anatomical basis, including the data of minute structure, physical properties, and chemical composition so far as these were then known. He then states the observations which have been made, and in respect to each question as it arises explains the several views which have been put forward, giving minute and full references to all the authors quoted. And he finally delivers a reasoned critical judgment, expounding the conclusion which may be arrived at, but not omitting to state plainly when necessary the limitations which

the lack of adequate evidence places on forming a decided judgment. He carefully recounts and as carefully criticises all the knowledge which can be gleaned about any question. If he feels unable to come to a decided conclusion he candidly says so. He always strives to be as exact and as clear as possible; conspicuous is the absence from his writings of loose expressions and ill-defined general views such as abound in so many of his predecessors. We may take any part of his great work as a trustworthy account of the knowledge of the time with regard to the questions therein treated."

SPALLANZANI

The year of Haller's death there appeared a memoir on digestion by the Italian Lazaro Spallanzani which established his place as one of the greatest physiologists of the eighteenth century. Born in southern Italy at Scandiano in 1729; after being liberally educated in letters, science and law, he gave attention to theology and took orders in the church. Although known as the Abbé Spallanzani, his connection with the offices of the Church was rather incidental; the labors of his life were those of a university professor and investigating naturalist. At the age of twenty-five he was appointed professor of logic, mathematics, and Greek at Reggio, but in 1760 was elected to the chair of natural history in Modena — a position better suited to his tastes and talents. Eight years later he accepted the invitation of Maria Theresa to become the professor of natural history at Pavia — a city which at that time belonged to Austria. Here he remained to the end of his life in 1799, having declined in 1785 a most flattering invitation from the University of Padua to succeed the great naturalist Vallisnieri as professor of natural history.

Spallanzani was " an investigator of singular power " and left his name connected with several scientific questions of historical interest. The question of spontaneous generation of life was much debated in his day, and to test the question Spallanzani made experiments by introducing decoctions of organic matter

into glass flasks with long slender bent necks which were thereafter hermetically sealed in a flame. The flasks were boiled to kill any living germs that might be in the fluids, and they remained permanently free from the development of any living matter. Suffice it to say that his experiments (1768, 1774) were regarded as conclusive in refuting the contention of Needham,

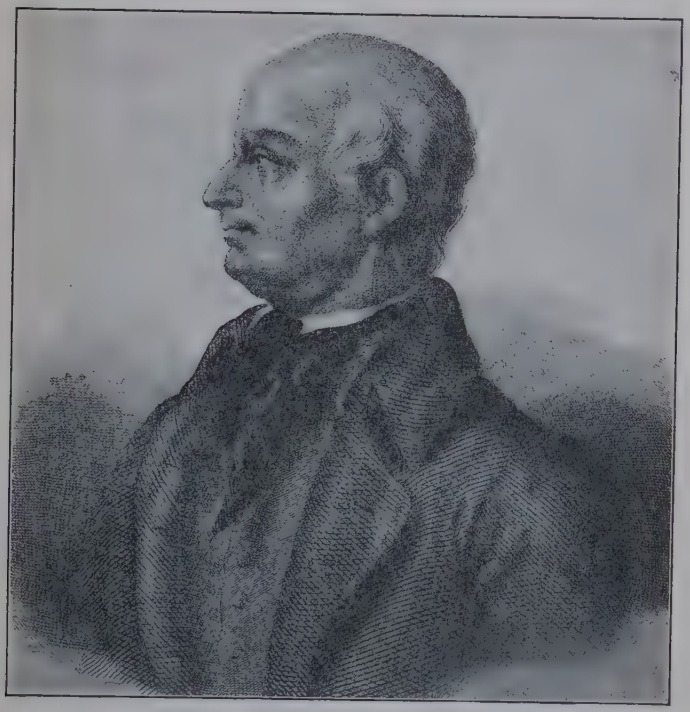

FIG. 133. — LAZZARO SPALLANZANI, 1729–1799. (A sketch from life by John Batta Busani.)

Buffon, and others who maintained that living organisms were spontaneously developed in such fluids. The whole question had a further hearing in the nineteenth century. Spallanzani made important observations on respiration in warm- and cold-blooded

animals as well as in hibernating animals. He showed for the first time a case of regeneration of nervous tissue by observing the new growth of the spinal cord in the regenerating tail of a lizard; he demonstrated that fresh muscular tissue excised from the body takes up oxygen and gives off carbonic acid gas, but here we are to speak only of his physiological observations on digestion.

Réaumur in 1752 had made studies on the action of the digestive fluids of birds; Spallanzani adopted the methods of Réaumur, reaffirmed and greatly extended his results. His ingenious methods of enclosing meat, bread, bone, grains of wheat, etc. in perforated receptacles — tubes with perforated wall and grating over the ends, perforated hollow spheres, etc. — allowed the free entrance of digestive juices and retained the food for observation of the effects of the digestive fluids. He recovered his receptacles " in the case of carnivorous birds through their being rejected by the mouth; in the case of other animals he opened the stomach after the lapse of a given time. He also made animals swallow pieces of meat or the like, so attached to threads or wires that he could after a while withdraw them from the stomach." And he did not omit to experiment on himself by swallowing small linen bags containing meat, bread, etc. By enclosing sponges in the perforated receptacles he obtained " gastric juice " and experimented with it outside the body. All this was an early attempt to investigate the chemistry of digestion but made at a time when chemistry was little developed. He missed detecting the acidity of the gastric juice, a property which years earlier had been noticed by Van Helmont. He did, however, discover the digestive action of saliva; he showed further that the gastric juice acts on food stuffs, reducing them to a state of solubility, and here the matter rested for a long time. He showed that the gastric juice will act effectually outside the body; obviously this was opposed to the doctrine of a vital force acting within the body and presiding over all physiological acts.

We owe to Spallanzani the experimental proof that in a wide range of animals — birds and mammals — the gastric juice, as

has been said, reduces the various constituents of their food to a state of solubility. This truth established through a very large number of various experiments [4] remained as "a definite addition never afterwards taken away from our knowledge of digestion."

PHYSIOLOGY OF THE NERVOUS SYSTEM

In the first part of the nineteenth century investigations on the function of certain nerves became a feature of physiology. It is generally known to high school pupils of today that the trunk of a spinal nerve is formed by the union of two bundles of fibres — one connected with the anterior and the other with the posterior portion of the spinal cord. These bundles are called respectively anterior and posterior roots. It was the fortune of Charles Bell to show that these nerve-roots are not only anatomically distinct but also different in function. After exposing the roots of spinal nerves in a rabbit he cut the posterior root and observed that no muscular movement followed upon mechanical stimulation or by cutting the fibers, but even touching the anterior root with his instruments produced movement of the muscles to which fibres of the corresponding nerve trunk were distributed. The conclusion drawn was that the nerve fibres of the anterior root belong to the motor, those of the posterior to the sensory type.

Although in letters to his brother George we have earlier references to it, this discovery was first expounded in a small pamphlet entitled *A New Idea of the Anatomy of the Brain and Nervous System* which was printed in 1811 for private distribution. It was expanded in his papers beginning in 1821, published in the Philosophical Transactions of the Royal Society of London, and was embodied in his work on the nervous system, published in 1830. Bell had observed the effects of stimulation on the anterior roots only and had assumed the sensory function of the posterior roots on theoretical grounds. The conclusive

[4] His first memoir on digestion, published in 1777, was afterwards expanded in his Dissertationi de fisica animali e vegetali, 1782 2 vols., especially those sections designated Della digestione degli animali.

experimental proof of the function of both roots was supplied by Magendie in 1822 and by Johannes Müller in 1831. The discovery fairly produced a sensation in the scientific world, and taken in its finished state was spoken of, as next to Harvey's, the most important physiological discovery up to that time.

FIG. 134. — SIR CHARLES BELL, 1774–1842. (Pettigrew.)

Sir Charles Bell (1774–1842) was a practitioner of surgery and a famous teacher of anatomy and surgery in London and afterwards in Edinburgh. He was an able surgeon of great manual dexterity; in 1815 he went to Brussels to help treat the wounded from the battle of Waterloo. In private life he was distinguished for "unpretending amenity, and simplicity of manners and deportment." After the announcement of his great discovery he was lionized in London and, although consideration and his great success there were most gratifying, in 1836 he ac-

cepted the invitation to fill the chair of surgery in Edinburgh, the city of his birth, saying that " London is a place to live in, but not to die in."

Charles Bell had unusual artistic ability and illustrated his numerous works on anatomy and surgery with striking pictures executed by himself. Among his general essays is a famous Bridgwater treatise on *The Hand: its Mechanism and Vital Endowments as Evincing Design,* 1833. Along with Lord Brougham he annotated and illustrated an edition of Paley's *Natural Theology* and this connects him from another angle with the history of biological thought.

MAGENDIE

In the hands of François Magendie physiology became emphatically experimental. " Repelled by the sterile discussions in which the vitalists and other doctrinaires of the day spent their intellectual activity, he was driven towards the other extreme, and arrived almost at the position of substituting experiment for thinking." [5] He likened himself to a rag-picker who goes about gathering morsels for his basket, and he left no great piece of constructive thinking. He was, however, incessantly busy with physiological experiments and contributed many facts to the science (effects of removal and section of the cerebellum; studies on blood and lymph, etc.). He founded the first periodical devoted exclusively to physiology, the *Journal de physiologie expérimentale,* 1821–1831.

In all Europe Magendie was the pioneer teacher of physiology by the experimental method. At the age of twenty (1803) he had been made prosector of the medical faculty and soon thereafter " demonstrator." He entered on the practice of medicine and for many years was attached as physician to the Hôtel de Dieu, but with all his other occupations, he found time to organize courses in experimental physiology which were well attended. His work attracted wide attention in scientific circles, and at the suggestion of Laplace, Montyon established, in 1817,

[5] Sir Michael Foster, *Claude Bernard,* 1899, p. 32.

a prize for experimental physiology which was awarded to Magendie. "Already," says Flourens, "his reputation and the novelty of his experiments attracted a large number of auditors to his courses." [6]

Magendie's greatest contribution to physiology according to Garrison "was his experimental proof (on a litter of puppies) of the truth of Bell's law, that the anterior roots of the spinal

FIG. 135. — FRANÇOIS MAGENDIE, 1783–1855.

nerves are motor, the posterior sensory, in function (1822). Through his bold vivisecting and lucid reasoning he arrived at a much clearer conception of these functions than Bell; and, in

[6] It should be noted that Purkinje was also an early teacher of physiology by experimental methods. In *The Scientific Monthly* for April, 1924, Dr. George R. Cowgill says that, at Breslau, in 1824, Purkinje began illustrating his lectures by a variety of experimental demonstrations: "so far as can be ascertained this was the first course in anything like experimental physiology" (p. 404). Although Magendie did not come to a professor's chair in the Collège de France until 1831, he had taught physiology with experimental demonstrations prior to 1817. It is difficult from sources at hand to determine when he began these courses. He says in his "Experimental Physiology," first published in 1816, that he had been teaching the subject for "fifteen" years. It is more likely that he began about 1807.

adjusting the two claims, it seems proper to assign to Bell priority of discovery and demonstration in reference to the anterior roots, to Magendie priority of conclusive demonstration and interpretation of the functions of both motor and sensory roots."

He acquires remembrance also as the teacher of Claude Bernard, who pursued Magendie's method of experimentation but planned all his work with thoughtful care to bring out the meaning of his investigations.

PERIOD OF JOHANNES MÜLLER

For biological science in Germany, Johannes Müller appears as much an institution as a man. Verworn says of him: "He is one of those monumental figures that the history of every science brings forth but once. They change the whole aspect of the field in which they work, and all later growth is influenced by their labors." Johannes Müller was a man of extraordinary personal qualities. Some have said, and not without reason, that there was something supernatural about Müller, for his whole appearance bore the stamp of the unusual. In his lectures his manner and his gestures reminded one of a Catholic priest. Early in life, before the disposition to devote himself to science became so overwhelming, he thought of entering the priesthood and there clung to him all his life some marks of the holy profession. His portrait with the massive head above the broad shoulders is shown in Fig. 136. In his highly intellectual face, says Virchow, we find "a trace of severity in his mouth and compressed lips, with the expression of most earnest thought on his brow and eyes and with the remembrance of a finished work in every wrinkle of his countenance."

Müller exercised a profound influence upon those who came into contact with him. He excited almost unbounded enthusiasm and veneration among his students. They were allowed to work close by his side in the laboratory, and so magnetic was his personality that he stimulated them powerfully and succeeded in transmitting to them some of his own enthusiasm and mental attitude as an investigator. As professor of anatomy and physi-

ology in Berlin he trained many gifted young men who attained eminence as scholars and university professors in Germany and other countries. Among his pupils may be mentioned: Jacob Heule (1809–1885); Theodor Schwann (1810–1882); Von Kölliker (1817–1905); Du Bois-Reymond (1818–1895); Brücke (1819–1892); Rudolph Virchow (1821–1913); and von Helmholtz (1821–1894). Helmholtz in speaking of Müller's influence on students paid this tribute to the grandeur of his teacher: "Whoever comes into contact with men of the first rank has an altered scale of values in life. Such intellectual contact is the most interesting event that life can offer."

Except the great influence of Johannes Müller on the progress of biology as a whole, his greatest service to physiology was to make it broadly comparative. He brought together in his famous textbook of physiology not only all that had previously been made known, carefully sifted and digested, but a mass of new information which was the result of his own investigations and those of his students and assistants. So rigorous were his scientific standards that he did not admit into this treatise anything that had been untested either by himself or by someone working in his laboratory. In physiology he stood on a higher and broader plane than was ever before attained. He employed every means at his command — experimentation, observations on simple as well as complex animals, the microscope, the discoveries of physics, chemistry, and psychology.

Verworn says of his monumental work, which appeared between 1833 and 1840 with the German title *Handbuch der physiologie des Menschens:* [7] "This work stands today unsurpassed in the genuinely philosophical manner in which the material, swollen to vast proportions by innumerable special researches, was for the first time sifted and elaborated into a unitary picture of the mechanism within the living organism. In this respect the *Handbuch* is today not only unsurpassed, but unequaled." The title *Handbook of Human Physiology* is too restricted; it

[7] Translated into English somewhat abridged, and published in London in 1842.

FIG. 136. — JOHANNES MÜLLER, 1801–1858. (From a painting by Carl Begas.)

is really a handbook of comparative physiology. As a mine of information it reminds one of the famous *Elementa* of Haller but is distinctly more modern; it represents physiology as it stood at the middle of the nineteenth century. He introduced into physiology the principles of psychology and, although strictly speaking he was not the first innovator in this respect, it is from the period of Johannes Müller that we associate recognition of the close relation between the operations of the mind and the physiology of the brain, which has come to occupy such a conspicuous position at the present time.

Müller's chair at Berlin included anatomy as well as physiology and he is very famous for morphological investigations well known to comparative anatomists. His investigations on some of the lower fishes and the echinoderms are classics. He rediscovered (1840) in the smooth dogfish shark the placental connection between the embryo and the walls of the oviduct of the mother, which had been described by Aristotle, but had for centuries remained unappreciated. His name is associated with the discovery of the Müllerian duct (1825).

In physiology his broadest generalization was the doctrine of specific nerve energies. This doctrine was more in the nature of an intellectual conception than a matter of scientific investigation. We recognize outside objects only by the sensations they produce on the nervous mechanism and Johannes Müller supposed that nerves have an inherent specific quality which is excited by objects of the external world or by certain physical agencies. Even mechanical stimulation of the optic nerve gives rise to sensations of light and color; the auditory nerve, however stimulated, gives rise to auditory sensations, etc. But the matter did not remain as Johannes Müller left it. This conception has been modified to agree with our better understanding of the architecture of the nervous system; in general the sensory nerves are regarded merely as conductors of waves of stimulation and the effects of their stimulation are received and interpreted by the cortical areas to which they are conducted.

Müller died in 1858, having reached the age of fifty-seven.

He had made physiology broadly comparative and imparted to it a modern tone. His extraordinary influence on the progress of biology gives him a prominent place in the history of nineteenth century biology. His total influence, like that of Ludwig, was the product of those who received inspiration and training at his hands as well as of his own work as an individual. His influence was continued through the teachings of his disciples.

TWO DIRECTIONS OF GROWTH

About the middle of the nineteenth century physiology began to show two marked tendencies of growth, and since that time it has progressed along two pathways — the physical and the chemical. A group of investigators arose — among whom the Weber brothers, Ludwig, du Bois-Reymond, and Helmholtz were leaders — devoted to the investigation of physiological phenomena by means of physical measurements and records made by machinery. With these men came into use the revolving drum upon which are recorded curves representing physiologic activities, the time markers, the myographs, the ingenious methods of recording blood flow and blood pressure, changes in respiration, the responses of muscle and nerve to various forms of stimulation, the rate of transmission of nerve currents, etc. Ludwig's kymograph and du Bois-Reymond's inductorium come to mind as examples.

The methods of investigating vital activities with the help of recording apparatus were soon introduced into psychology, botany, and zoölogy, and, as might have been predicted, the extension of knowledge through experiments of this nature has been very great indeed. It is obvious that permanent records made by mechanical devices will rule out many errors, and afford opportunity to study at leisure phenomena that occupy a very brief space of time.

The second marked line of physiological investigation has been in the domain of chemistry. As Garrison remarked: "The chemical tendency in modern experimental physiology which led up to the magnificent work of Claude Bernard and Pasteur, was

initiated by Liebig and Wöhler in Germany, and by Dumas and Chevreul in France." Wöhler, in 1828, effected in the laboratory an artificial synthesis of urea and gave a great impulse to the investigation of organic compounds. This was the first time an organic substance had been built up artificially and it led to the "brilliant line of synthetic work, of which the highest point has so far been reached by Emil Fischer." Consideration of the work of Liebig, Kühne and others in chemical physiology, although important, would unduly prolong our story at this point; later, however, something will be said about the investigations of Claude Bernard in chemical physiology.

The union of these two tendencies into the physico-chemical aspects of physiology has determined the modern view of the nature of vital activities; these are now regarded as being in their ultimate analysis, due to physical and chemical changes taking place within the living substance. All along, the physico-chemical conception has been in conflict with that of vitalism and of the supposed duality between the physical body and the life that is manifested in it. The vitalists have had many controversies with those who make their interpretations of vital manifestations along physico-chemical lines. In previous pages it has been pointed out that "vitalism" in the hands of the immediate successors of Haller became not only highly speculative but highly mystical, tending to obscure any close scientific analysis of vital activities. Johannes Müller was to a certain extent a vitalist but his vitalism was of a more acceptable type. He thought certain changes in the body might be due to a living force, but he did not deny the possibility of the transformation of the vital into other forms of energy and upon this foundation there was built the conception that there is in the bodies of living beings a particular transformation-form of energy, not a mystical vital force, that presides over all manifestations of life.

Having pointed out the two directions of growth of physiology we return to consider the contributions of certain individuals, Ludwig, du Bois-Reymond, and Helmholtz, who carried forward

the work begun by Müller — and, finally, the work of Claude Bernard who was *sui generis*, the great physiological investigator of the nineteenth century.

LUDWIG

Carl Ludwig (1816–1895) was never a pupil in Müller's laboratory, but he received stimulus from personal contact as well as from his writings and researches, and in this sense was one

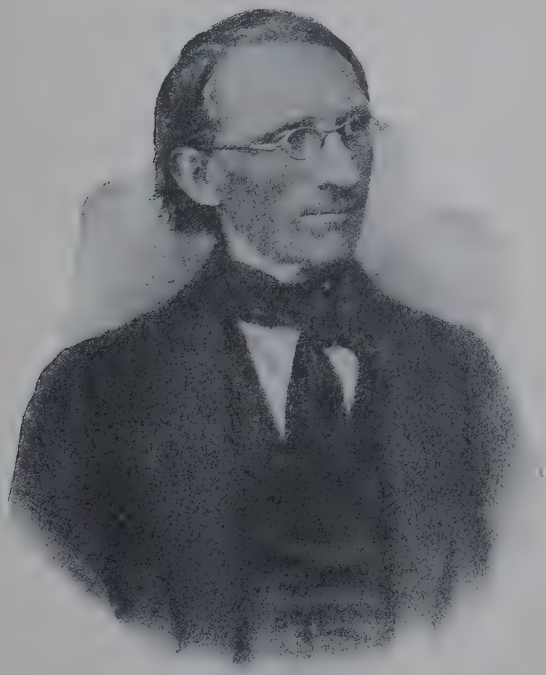

Fig. 137. — Carl Ludwig, 1816–1895.

of Müller's disciples. For many years Ludwig lectured and conducted a laboratory of research at the University of Leipzig. His fame as a teacher of physiology was world-wide and he at-

tracted to the Leipzig laboratory many highly gifted young men of various nationalities. He had a winning personality and a most generous spirit of helpfulness, making him "perhaps the greatest teacher of physiology who ever lived." He was a true investigator and published, besides others, important findings on the blood and its circulation, but for the most part he was content to publish through his students. His individual scientific bibliography is not a long one. He selected the problems for the students in his laboratory, directed their work into fruitful channels, critically reviewed their scientific product, and often wrote out in final form their papers for publication — adding discoveries of his own for which he sought no credit. Honest, unselfish, sympathetic, stimulating, and training a large number of physiologists, he exercised a beneficent influence on the progress of physiology.

DU BOIS-REYMOND

Emil du Bois-Reymond, although born in Berlin and reckoned as one of the great German physiologists, was of French extraction. "His father belonged to Neuchâtel, his mother was of Huguenot descent and he spoke of himself as 'being of pure Celtic blood.'" After his early education in the French college of Berlin and then at Neuchâtel, he entered the University of Berlin in 1836, where after a period of devotion to historical studies he transferred to medicine and in due time came under the influence of Johannes Müller. In 1840 Müller selected him as one of his assistants and for eighteen years thereafter his life and labors were closely associated with that great teacher. The position which Müller filled so acceptably at Berlin had two lines of duty — anatomy and physiology — but after his death in 1858 the work was divided into a department of anatomy which fell to K. B. Reichert, and a department of physiology to which du Bois-Reymond was appointed. The latter held this position during the rest of his life, at first working under the limitations of inadequate accommodations, but he secured a commodious and well-equipped laboratory which was opened in 1877. Here with

his devoted *Diener* and his able colleague, Johann Gad, he carried on as best he could the traditions of Johannes Müller. He died at Berlin, the city of his birth and adoption, in 1896. For many years he exerted a great influence as a teacher. It was the privilege of the writer to listen to almost his last lectures on the

Fig. 138. — Emil du Bois-Reymond, 1818–1896.

subject of animal electricity. The student-attitude of respect and sympathy for the then veteran of science amounted to more than friendly regard; by marked attention when his reading was faint, they paid a tribute to the man whom they recognized not only as the world-authority on the subject of his lectures but as the successor of Johannes Müller.

In physiological research du Bois-Reymond chiefly employed the methods of physics. He investigated muscle-nerve preparations, the phenomena of diffusion, and above all, the phenomena of animal electricity. His graduating thesis (1843) was on *Electrical Fishes* — a subject assigned to him by Müller and worked out under his direction. For forty years he continued to make contributions in the field of electro-physiology, the last part of his *Researches on Animal Electricity* appearing in 1884.

His occasional papers and addresses are models of clear-cut thinking and expression. His memorial address on Johannes Müller (*Gedachtnissrede auf Johannes Müller*) is the best single reference on Müller's services to science. His memoir on Helmholtz is the tribute of a life-long friend; for years the laboratories of the two men were in the same building. Two of his general essays — those on the *Limits of Natural Science* (1872) and the *Seven World-Riddles* have attracted especial attention.

HELMHOLTZ

Hermann von Helmholtz (1821–1894) was a man of unusual intellectual gifts. In whatever field of science he undertook investigations, he left published results that stand in the first rank. He is perhaps more commonly thought of as a physicist, but we should remember that up to the age of fifty his teaching and investigation were chiefly in the field of physiology. Trained in medicine in the University of Berlin, and especially in physiology under Johannes Müller, he wished to follow scientific pursuits. "As his people were poor and could not afford to allow him to follow a purely scientific career, he became a military surgeon of the Prussian army." Here his passion for research asserted itself and he made scientific contributions that brought him into notice, and when he was twenty-eight years of age he was called to the University of Königsberg. From the ages of twenty-eight to fifty he was, successively, professor of physiology and pathology at Königsberg (1849–1855); of anatomy and physiology at Bonn (1855–1858); and of physiology at Heidelberg (1858–1871). Then, at the age of fifty, he went to Berlin

where for twenty-three years he was famous as professor of physics. In 1887 he became director of the Physico-Technical Institute at Charlottenburg near Berlin, and he held the two positions concurrently until his death in 1894.

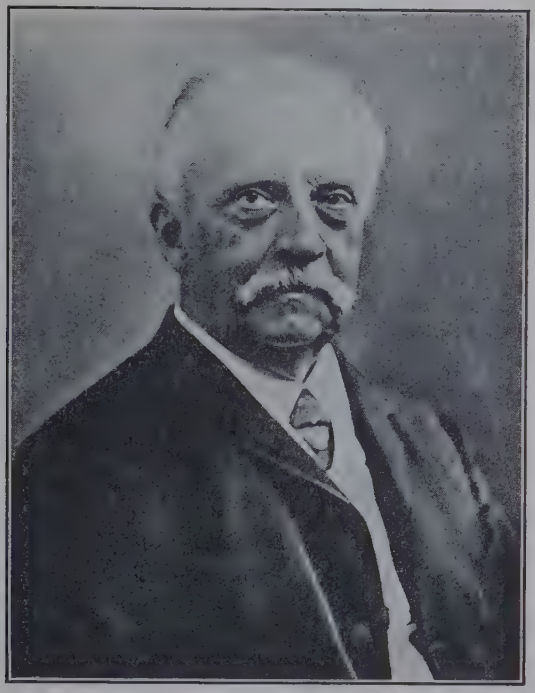

FIG. 139. — HERMAN VON HELMHOLTZ, 1821–1894.

In his graduating thesis (1842) he announced the discovery of nerve-cells in the ganglia of leeches and crustacea. In 1847, before he was invited to his first professorship, he read to the Physical Society of Berlin a paper on the conservation of energy [8] which is now regarded as one of the basal publications on that doctrine. Previous to Helmholtz's paper the principle of conser-

[8] *Die Erhaltung der Kraft*, 1847.

vation of energy had been applied to physiology by Robert Meyer and to physical phenomena by Joule, but "Helmholtz made it of universal application." On assuming his university professorship he threw himself into the investigation of physiological problems by the methods of physics. About 1850 he measured the velocity of the nervous impulse, a feat which ten years earlier Johannes Müller had declared to be impossible. He gave especial attention to physiological optics and acoustics. While at Königsberg he invented the well-known optical instruments, the ophthalmoscope (1851) and the ophthalmometer (1852), used today in medical practice and in laboratories of physics, physiology and psychology. Of his *Handbook of Physiological Optics* (1856–1866), the physiologist McKendrick says: "It is the most important work that has appeared on the physiology and physics of vision." But in merit, and as a permanent classic, his work in optics is surpassed by that on *Sensations of Tone*[9] (*Tonempfindungen,* 1863).

Of his truly notable work in physics this is not the place to speak, but a word as to his occasional addresses and essays will be in keeping. "As a lecturer on 'popular science' Helmholtz was approached only by Huxley, Tyndall, and Ernst Mach. His writings in this field have an elevation and dignity, a genial command of vast resources, which is peculiarly his own." (Garrison). "His life from first to last was one of devotion to science, and he must be accounted, on intellectual grounds, one of the foremost men of the nineteenth century."

BERNARD

To the Frenchman, Claude Bernard, belongs a position of extraordinary eminence in the history of physiology. In some of the general outlines on the rise of physiology, for example, that of Verworn,[10] he has been rather slighted, and his rank in

[9] *Die Lehre von den Tonempfindungen als physiologische Grundlage für die Theorie der Musik.*

[10] Max Verworn: *General Physiology.* The English translation by Frederic S. Lee contains an excellent exposition of the history of physiology. This is probably the most generally read sketch of the subject. Notwithstanding its

the history of physiology has not been fully appreciated by biologists. Although working in a different line from that of Ludwig and Helmholtz, he was probably the foremost representative of experimental physiology in the last half of the nineteenth century. Indeed, the American physiologist Howell says he is entitled by his discoveries "to be ranked as the greatest physiologist that the world has produced." [11] A candid reading of his lectures on Physiology,[12] covering a wide range of topics such as internal secretions, toxic substances, action of sympathetic nerves, digestion, animal heat, etc., will show that his exposition of the principles of physiology is brilliant, and, outside his lectures, his special researches are of the highest scientific value. In his Introduction to the study of experimental physiology (*Introduction à l'étude de la médecine expérimentale,* 1855) and his later publication on the same subject (1865) he appears as the lawgiver of experimental procedure in physiology. These writings are meditations on the mental attitude of the investigator as well as on methods, that might well be read today by all biological experimenters.

Claude Bernard was always interrogating nature through experiment; he said that the science of observation is passive; that of experiment is active. In the field of general biology his treatise on the *Phenomena of Life common to Animals and Plants* (*Leçons sur les phénomènes de la vie, communs aux animaux et aux végétaux,* 1878) was the first great treatise on general physiology and opened subjects which have such vogue today. It is a recognized classic and had great influence in advancing the knowledge of vital activities.

The attainments of any investigator are so dependent on personal character and educational advantages, that one wishes to

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high merits, it does not seem to the writer that the extraordinary importance of Bernard's investigations have been sufficiently recognized.

[11] Article *Physiology* by William H. Howell in *Science and Learning in France,* p. 175.

[12] Carefully taken down by his students as delivered by Bernard, revised by his own hand and published through a series of years in seventeen octavo volumes of *Leçons.*

know something about the circumstances that contributed to the progress of this extraordinary man. He was born at Saint-Julien, department of the Rhône, in 1813. His father was the owner of a small grape-producing estate and derived his income chiefly from making wine. "As a child he must have been bright, for the Curé took him under his special charge, making him a choir boy and teaching him Latin." He pursued studies at the Jesuit school in the nearby village of Villefranche, but as this school was not very advanced, he went to the college at Lyons to complete studies for a bachelor's degree. Before he was graduated, for some unknown reason (not, however, lack of family resources [13]) he engaged himself to a pharmacist, and for about two years he dispensed medicine and acquired a knowledge of practical pharmacy. In common with many young Frenchmen of the day, he had literary aspirations and wrote a vaudeville comedy entitled *La Rose du Rhône* "which was not only accepted, but had a certain success on the boards, though it was never printed." "Encouraged by the result of his first effort," he wrote *Arthur de Bretagne,* a tragedy of five acts, and with this production as an earnest of what he could do he determined to seek his fortune in Paris as a writer. He carried a letter of introduction from one of the faculty at Lyons to the eminent critic, Saint-Marc Girardin, a professor at the Sorbonne. The critic discovered literary merits in the play, but with the wisdom of worldly experience advised Bernard to study medicine as more secure means of livelihood. The acceptance of this advice threw Claude Bernard into medicine, and whatever literature may have lost, science gained.

When Bernard began his medical studies, Magendie was of all Europe the striking figure in experimental physiology; he lectured at both the Sorbonne and the Collège de France. Bernard's remarkable manual dexterity caught the attention of Magendie and he chose him for his assistant at the Collège de France. Here, the superb way in which the assistant conducted the lecture demonstrations, led Magendie to exclaim at the close

[13] See *Claude Bernard* by Sir Michael Foster, 1899.

of one of his lectures, " You are a better man than I." Magendie's influence on Bernard's method of investigation was more general than specific. As previously stated, Magendie was an advocate of experiment to such an extent that he almost substituted experiment for thinking. Bernard, indeed, was stimulated by Magendie and in his later life made many affectionate allusions to him, but the pupil with a higher quality of intellect saw the futility of experiments without a definite plan. In contrast with those of his teacher, his experiments were planned to some specific end and were guided by previous meditation and thought.

Claude Bernard was graduated with the degree of Doctor of Medicine in 1843, presenting as his thesis a study on the gastric juice. Very soon he gave such evidences of his striking endowments that a position in general physiology was especially created for him at the Sorbonne. Also, Magendie was growing old, and, in 1847, his increasing infirmities led to the appointment of Bernard as his deputy at the Collège de France, and when Magendie died in 1855, Bernard was chosen as his successor. He now lectured both at the Sorbonne and at the Collège de France and during the early years of double duties his activity was enormous.

The thoughtful face of Bernard is shown in Fig. 140. He was one of those reflective, silent men whose natures are difficult to fathom and who are too frequently misunderstood. A domestic infelicity, which led to the separation of himself and family, added to his isolation and loneliness. When touched by the social spirit, he charmed people by his conversation as well as by his personality. He was admired by Emperor Napoleon Third, through whose influence Bernard acquired two fine laboratories. Sir Michael Foster, one of his biographers, describes him thus: " Tall in stature, with a fine presence, with a noble head, the eyes full at once of thought and kindness, he drew the look of observers upon him wherever he appeared. As he walked the streets passers-by might be heard to say, ' I wonder who that is; he must be some distinguished man.' "

Among his intimate friends were numbered Berthelot the

chemist, Renan the philosopher, and Gambetta the statesman. He was adored by his pupils; a large number of young men from France and other countries came to Paris especially to receive his instruction. Among those whom he trained by example and precept may be mentioned Willy Kühne, Marey, Francois-Franck, Paul Bert, Richet, Dastre, who in their turn have contributed effectively to the advancement of physiology.

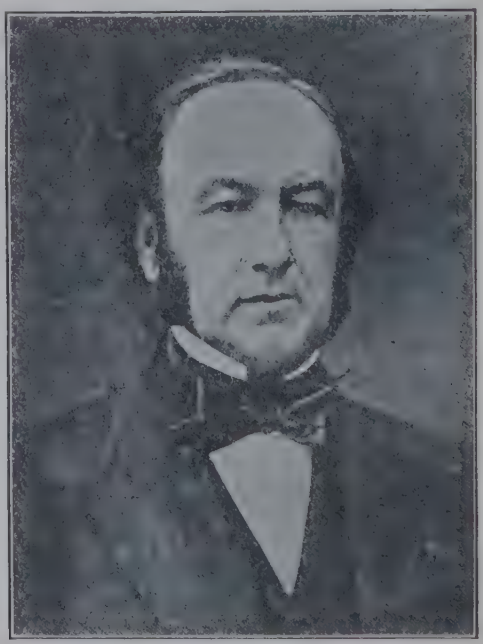

FIG. 140. — CLAUDE BERNARD, 1813–1878.

Bernard had accomplished most of his great experimental work by the year 1860 when he was forty-seven years of age, but he continued to lecture with great brilliancy and to publish important writings up to the year of his death. In 1868 he was elected to the French Academy, and thereby became one of the "Forty Immortals." He died in 1878 and was accorded the signal honor of a public funeral, at the expense of the State —

an unusual recognition of his great eminence, since this was the first time in France that such an honor had been bestowed on a scientific man.

HIS GREAT DISCOVERIES

Bernard made three monumental discoveries which so completely changed the outlook of physiology that they might even be spoken of as revolutionary. They opened new views of internal secretion; of the regulation of bodily activities through the medium of the nervous system; and of digestion by the pancreatic juice. It is given to some men to make discoveries of important individual facts the full significance of which is pointed out by later investigations, but it is to be said of Claude Bernard that he brought his three greatest discoveries to their logical conclusion. It would be beyond the purpose of this book to attempt a scientific analysis of these researches, but since they had such a sweeping influence on physiology as a whole they are of historical importance. The period of his life between the ages of thirty-five and forty-five was one of prodigious productivity; several researches were carried on concurrently and except that they came to fruition during this time of his life they cannot be very well separated chronologically.

His most important discovery was that of the formation of glycogen within the liver. The initial step was his demonstration of the occurrence of sugar in the hepatic vein of a dog fed on a strictly meat diet, and in dogs in a starving condition. From this he went on to demonstrate that a simple decoction of liver substance invariably contains dextrose sugar — and to discover that this sugar comes from a substance which, in 1857, he named glycogen. The discovery that the liver actually manufactures a carbohydrate substance, convertible into sugar, overthrew the prevailing view " that the animal body, in contrast with the plant received its organic substances ready made and could not construct any of them." Bernard's demonstration of the constructive powers of animal tissues was essentially the first as well as the most complete study of internal secretions, and it " excited

great interest throughout the scientific world." Bernard himself supplied the name "internal secretion" and his work formed the starting-point of those studies leading through Bayliss, Pavloff, and many others to the modern doctrine of hormones. The medical applications of his discovery of "liver sugar" to the disease diabetes belong to medical history.

Claude Bernard began his studies of sympathetic nerves in connection with an investigation in the production of animal heat. It was known that in some way the sympathetic nerves govern the calibre of blood vessels, and he set out to determine how the temperature of a part of the body is affected by the section of one of these nerves. He chose first the cervical sympathetic of the rabbit, branches of which go to the blood vessels of the ear. The rabbit's ear is large, translucent, and well adapted for observations of this nature. On section of the nerve he got an unexpected result; the ear became red instead of pale, and showed a considerable rise in temperature. These results were communicated in 1851 and the following year Brown-Séquard, then in the United States, repeated the experiment, and furthermore, stimulated the cut end of the nerve with a galvanic current. The result of this experiment was to cause the ear to become pale and to fall in temperature. Brown-Séquard concluded that the result reported by Bernard arose from a paralysis of muscles which caused the blood vessels to dilate. Quite independently Bernard stimulated the cut end of the nerve and observed a reduction of the blood supply and a fall in the temperature and hit upon the true explanation, *viz.* that the results were not the consequence of paralysis (as Brown-Séquard supposed) but were owing to release of the circular muscles of the blood vessels from the nervous stimulus conducted along the nerve fibres and holding the muscles in a normal state of contraction. When the nerve current was removed by section of the nerve, the muscles returned to a state of physiologic extension and the calibre of the blood vessels was enlarged. Electrical stimulation of the cut end of the nerve supplied a new stimulus which was conducted along the nerve fibres and being delivered to the cir-

cular muscles caused them to contract and reduce the size of the blood vessels. The nerves supplying the coat of smooth muscle tissue of all blood vessels are called vaso-motor nerves. Bernard by subsequent experiments on the chorda tympani, a branch of the facial nerve, demonstrated the existence of vaso-constrictors and vaso-dilators. These discoveries opened the way to the whole subject of nervous regulation of blood vessels, and as such was one of the great physiological advances of the nineteenth century.

His investigations on the part played by the pancreatic juice in digestion were also of great value. They were the first in point of time of his three greatest contributions to physiology. He demonstrated the three-fold action of the pancreatic juice on food stuffs — the carbohydrates, the proteids, and the fats. After his researches the pancreatic juice was recognized as more complex and more effective than the gastric juice — a sort of universal digester with enzymes acting on the different classes of food stuffs. His graduating thesis for the degree of Doctor of Medicine had been on the gastric juice, especially on its influence on sugar, and by his researches on the pancreatic juice and on the production of sugar by the liver, he completed the work which he had opened at the beginning of his career.

To sum up briefly the chief results of his investigations: he made contributions of signal value on the subject of internal secretions, on nervous regulation of blood supply to all tissues and on the phenomena of digestion and nutrition. Besides this he investigated the physiological action of various poisons (curare, carbon monoxide and others). He made the best exposition of the mental attitude of the investigator towards his problems, as well as providing him with the best methods to be used in physiological experiments, and he opened the subject of phenomena of life common to animals and plants. No other single individual has made more brilliant contributions to the science of physiology.

Physiology was now established on modern lines and there arose new leaders to carry forward the work. The eminent men

of physiology since Bernard are numerous and one cannot make distinctions among peers, each eminent in his own sphere of activity. Among those come to mind Paul Bert, the successor of Bernard; Richert, the introducer of anaphylaxis; Angelo Mosso in Italy, Brücke in Vienna, Vogt and Verworn in Germany, Michael Foster and Burdon-Sanderson in England, Henry P. Bowditch and Chittenden in the United States, — modern leaders, whose investigations have promoted advance, whose teaching and example have stimulated their many disciples, and whose clear exposition of the facts and theories of physiology have added much to the dignity of the science.

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INDEX

A

Abernethy, 338
Adelard of Bath, 80–81
Agassiz, Louis, 331
Albert the Great
  (see, Magnus, Albertus)
Alcmæon, 43
Aldrovandi, Ulisse, 298–300, 301
Alexandria,
  center of Greek science and culture, 39–46
  library at, 40, 41
Alhazan, on enlargement of objects, 197
American Association for Advancement of Science, scientific historical section, 6
American Historical Association, scientific section established, 5–6
Amici, 413, 431
Amœba, 219, 220, 268
Anatomy
  (see also, Circulatory system; Physiology)
  anatomical theater at Padua, 184
  Berengario da Carpè's work, 161–163
  comparative, 334–359
  human and animal structure, 340–342
  human and bird skeletons, 287, 288
  defined, 335
  De humani corporis fabrica, 168
  dissection legalized, 156
  drawings, early use of, 159
  early sketches, 104
  early studies, 43
  Erasistratus, student of, 45
  Eustachi's contributions, 175–177
  Fallopio's contributions, 175–176
  Galen's contributions, 63, 65–67
  Harvey's work in relation to new era, 179, 182
  Herophilus, student of, 44–45
  Leonardo da Vinci on, 159–162
  Malpighi's work, 229–240
  Mondino's contributions, 156–158
  "physiological," defined, 337
  sixteenth century advancement, 153
  Swammerdam's studies, 243–250
  Vesalius' work, 166–174
  Vicq-d'Azyr's work, 340–342
Animals
  (see also, Zoölogy)
  aquatic, Rondelet on, 288
  classification, 330–331
    Aristotle's, 31
    Cuvier's, 322, 325–326
    Lamarck's, 323–325
    Leuckart's, 329
    Linnæus', 310, 317–321
    Linnæus' reformed, 322–333
    comparative anatomy, 334–359
  early pictures of, 13, 14
  Gesner's study, 290–298
  Linnæus' work, 310, 317–321
  Magnus' writings, 92–94
  pictures in manuscripts, 103–104
  Pliny's writings on, 51
  Scale of Being, 322
  von Siebold on, 327–328
  Wotton on, 284–285
Anti-toxins, early investigations, 3
Aphids, Bonnet's observations, 266
Aquinas, Thomas, 91
Arabs, scientific activities, 83–88
Archimedes, 40
Architecture, of thirteenth century, 90
Aristotle, 9, 13, 18, 21–34, 38
  as writer, 50
  evolution theory approached, 32–33
  library of, 33–34
  Lyceum of, 21, 31, 33, 34
  rank as scientist, 71
  zoölogical observations, 20–21, 26–32
Art, of thirteenth century, 90
Associations, scientific, formed during seventeenth century, 226
Astronomy, Copernicus on, 154

Atwell, Charles B., acknowledgement to, iv
Aurignacean culture-period, 11
Averroës, 85–87
Avicenna, 84

B

Bacon, Francis, 96, 181–182, 227
Bacon, Roger, 72, 91, 97
  on magnifying properties, 197
Bacteriology, 224
  (see also, Micro-organisms)
  early investigations, 3
  Leeuwenhoek,
    discoveries in, 214–216
    mouth studies, 214
Balbiani, 224
Banks, Joseph (Sir), 376
Bartholomæus Anglicus, 25, 99–101, 102
Bartholomæus de Glanville, 99
Bartholomew of England
  (see, Bartholomæus Anglicus)
Basket star, 295
Bauhin, Casper, 136, 144, 148–149, 311, 360, 361, 362, 436
Bauhin, Gaspard
  (see, Bauhin, Casper)
Bauhin, J., 288
Bean, sketch from *Materia medica*, (Fig. 9) 60
Bees, Swammerdam's studies, 244–245
Bell, Charles (Sir), 447–449
Belon, Pierre, 286–288, 334
Benedict of Nursia, 78
Berengario da Carpi, 156, 161–163
Bernard, Claude, 68, 333, 455, 457, 462–470
Bernhardi, 389
Biblia naturæ, 243, 246, 247, 256
Bidpai, *Buch der Weisheit*, 115, 117
Binet, 224
Biology
  (see also, Natural history)
  amoeba, 219, 220
  animal forms multiplied by fission, 281
  bacteria, 214–216
  classification of Linnæus, 310, 317–321
    reformed, 322–333
  Ehrenberg's "Infusoria as Perfect Organisms," 221
  from Linnæus to Darwin, 332–333
  hydra, Trembley's studies, 278
  insects and others, 256–282
  Leeuwenhoek's contributions, 211–218, 250–253
  micro-organisms, importance, 224
  minute animals studied, 277
  Müller's contributions, 220–221, (Fig. 60) 222
  protozoa, 211–213, 219, 224
  public interest in, begun, 3
  sixteenth century advancement, 153
  terminology,
    Bauhin's, 311
    Linnæus', 310, 317–321
Birds,
  Belon on, 286–288, 334
  embryonic development,
    Aldrovandi on, 300
    Aristotle on, 20, 29–30
    Haller on, 442
    Malpighi on, 238–239
    Pliny on, 50–51
    Turner on, 285
Blood
  (see, Circulatory system)
Bock, Hieronymus, 25, 71, 137–139, 360, 436
  influenced by Brunfels, 129
Boerhaave, 313, 336
Bones,
  Camper's studies, 336
  Luz, 174
Bonnet, Charles, 262, 265–266
Books,
  (see also, Libraries; Records)
  Aristotle's library, 34
  copying of, in Alexandria, 42
  Dioscoridean manuscripts, 58
  fifteenth century, 104–125
  first publications, 104
  illustrations,
    first printed, 104–125
    in manuscripts, 103–104
  "knowledge-books" of thirteenth century, 91–92, 283
  of Albertus Magnus, 92
  of Middle Ages, 78
  on herbals, 127, 135
  printing introduced, 104
  scientific, seventeenth century, 227–228

scientific textbooks improved, 416, 419, 423
"Scriptoria," 42
use of the cyclopædia, 102
Borelli, 232, 337
Botany
(see also, Herbals, Natural history; Plants; Science)
Brown's work, 375–381
de Candolle's work, 372–375
de Jussieu family, contributions, 368–371
from Linnæus to Schleiden, 360–381
Grew's work, 384–388
growth and development, during sixteenth century, 126–152
Hale's work, 397–400
Hofmeister's work, 427–435
Ingen-Housz on, 400
Linnæus' work, 310, 313–314, 317–321, 364–368
Magnus' contributions, 92–96
Malpighi's work, 382–384, 385, 387–388
Nägeli's work, 393–396
plant anatomy, Linnæus to Sachs, 382–415
Ray's work, 363
Sach's investigations, 407–409
Theophrastus, "father of," 9, 38
vegetable physiology developed, 397–415
von Mohl's work, 389–392
zoölogy, similarity of development, 7
Brain, Galen's observations, 66–68
Brandt, entomologist, 277
"Breidenbach's Travels," illustrations in, 115, 116
Brock, John, translator of Galen, 69, 70
Brooks, on Gesner, 292
Brown, Robert, 367, 368, 375–381, 417, 421, 431, 436
Brunfels, Otto, 128–129, 134, 436
writings of, 123, 126–131
Buch der Natur
(see, *Puch der Natur*)
Buch der Weisheit, 115, 117
Buffon, 340
on spontaneous generation, 218
Bütschli, 224

C

Cameraius, Rudolph J., 136, 410–411
Camper, Pieter, 335–337
Capella, 102
Capillary circulation
(see, Circulatory system)
Carpi, 65
Carus,
on influence of scientists, 101
on *Physiologus*, 76
Cassiodorus, 58, 75, 78, 102
Cell-theory, 333, 382, 392–395, 418, 427
early investigations, 4
establishment, 273
formulated, 1838, 222
Cephalopods, Aristotle on, 27, 28
Cesalpino, Andrea, 144, 150–152, 193, 362
Charlemagne, educational work, 79–80
Chicks
(see, Birds)
Circulatory system
(see also, Anatomy; Heart)
capillary circulation, 217, 218
Cesalpino on, 193
effect of establishment, 439
Hale's investigations, 399–401
Harvey's study of, 183, 185, 186–189, 193–195
Leeuwenhoek's discoveries, 217
Leonardo da Vinci on, 190
red corpuscles,
Leeuwenhoek's observations, 252
Malpighi's observations, 252
Swammerdam's discovery, 243
Servetus on, 192
Vesalius on, 191, 192
Claparède, 224
Clusius, 288, 302
Cockchafer, Straus-Dürckheim on, 269–271
Colombo, 177
Colonna, Fabio, 136
Columbus, Realdus, 190, 192–193
Conrad von Megenberg, 94, 101, 102, 105, 109
Cooper, Astley (Sir), 338
Cope, E. D., 358–359
Copernicus, Nicholas,
"Revolutions of the Heavenly Bodies," 154

Corals, 281, 350, 369
Cordus, Valerius, 25, 71, 139–144, 360, 436
  contributions to botany, 130
Crateuas, 54, 55, 95
Crew, Henry, acknowledgement to, iv
Crô-Magnons, 13–18
Crusades, 89–90
Crustacea, 350
  Aristotle on, 28
  Harvey's observations, 187
  Newport on, 272
Cuvier, Georges, 24, 269, 322, 325–326, 342–349
Cyclopædia of Vincent, 97–99, 108
Cytology, development of, 7

D

d'Aléchamps, 136
Dante, 90
Daremberg, Charles, on Galen, 68
Darwin, Charles, 3, 415
  on Aristotle, 25
de Bary, 436
de Calcar, John Stephen, 168
de Candolle, A. Casimir, 373, 374
de Candolle, Alphonse, 373, 374
de Candolle, Augustin P., 366, 368, 372–375, 436
de Candolle, Pyramus, 374
Deer,
  Gesner's sketch, 294
  prehistoric sketch, 16
  red, prehistoric sketch, 15–16
de Geer, Charles, 262, 268, (Fig. 77) 268
de Graaf, embryonic studies, 242
de Jussieu, Adrien, 368
de Jussieu, Antoine L., 366, 368, 368–371
de Jussieu, Bernard, 367, 368–369
de Jussieu family, 368–371, 436
de Lacaze-Duthiers, Henri, 351–353
de l'Ecluse, Charles, 136, 144
de l'Obel, Mathias, 136, 144, 149, 288
de Saussure, Théodore, 403, 405–407, 436
Descartes, 181
  earliest printed pictures of microscopes, 200, 201
de Tournefort, Joseph Pitton, 362
Digestive fluids, 446
Digges, 198
Diologus Creaturarum, illustrations in, 115, 117
Dioscorides, Pedanois, 44, 47, 51, 54–62
  botanical contributions, 54–55, (Fig. 9) 60
  commentaries on, 136
  Materia medica, 54–62
Disease
  germ theory of, 3
    Fracastorius on, 202
Dissection,
  early use of, 43
  Galen's use of, 66–70
  limitations on work, 155
  legalized, 156
  Lyonet's work on insects, 257–261
  Swammerdam's work, 242, 245
Dodoens, 136
Doeflein, 224
du Bois-Reymond, Emil, 455, 458–460
Dufour, Léon, 272
Dujardin, 223

E

"Ebers Papyrus," 9
Ecology, Theophrastus' observations, 38
Education,
  Charlemagne's influence, 79–80
  of thirteenth century, 91
  religion, relation during seventh and eighth centuries, 79–80
  revision of Albertus Magnus, 97
Ehrenberg, 221–222, (Fig. 61) 223
Embryology,
  bird development,
    Aldrovandi on, 300
    Aristotle on, 20, 29–30
    Haller on, 442
    Malpighi on, 238–239
    Pliny on, 50–51
  early investigations, 4
  Newport's recognition, 272
  plant studies, 378, 409–413, 431
  spermatozoa discovered, 218
  Swammerdam on, 248
Entomology, 275, 276
Erasistratus, 40, 43–45
Euclid, 40

Eustachi, Bartolomeo, 175–177, (Fig. 43) 178
Evolution,
Aristotle's approach to theory of, 32
organic, 396, 433
early studies, 7
revival in 1859, 3

F

Fabre, Henri, 272, 276
Fabrica, by Vesalius, 168–173
Fabricius, *ab Aquapendente,* 182–183
Fallopio, Gabrielle, 175–176
Forel, entomologist, 277
Foster, Michael (Sir), 5
on Bernard, 465
on Malpighi, 239
on Vesalius, 167
Fox, sketch from *Garten der Gesundheit,* 124
Fracastorius, 202
Frazer, on early relation of magic and science, 17
Frederick II, influence on science, 156
Frey, 302
Fuchs, Leonard, 131–135, 436

G

Gærtner, Joseph, 368, 371–372
Galen, 44, 47, 51, 62–71, 436
limitations on work of, 155, 180
Natural Faculties, 20, 68, 70
on Dioscorides, 56
rank as scientist, 71, 438
view of circulatory system, 190
Galileo, 181, 182
inventor of microscope, 198, 199
Galton, heredity studies, 4
Garrison, scientific contributions, 5
Gart
(see, *Garten der Gesundheit*)
Garten der Gesundheit, 107, 114, 119–125
Gärtner, H. F., 412
Gegenbaur, Karl, 357–358
Generation,
alteration of, 432
aphids, 266
of plants, 409–413, 434
theory of spontaneous, 218, 248, 250, 347, 444
Gerard, John, 136
Germ theory of disease, 3, 202
Gesner, Conrad, 136, 142, 145–146, 283, 289–298, 301
Gestelt der Welt, 110
Ghini, Luca, 151
Gilbert, 181
Giliani, Alessandra, 159
Giotto, 90
Goat-moth
(see, Willow moth)
Goebel, 436
Graber, entomologist, 277
Gray, Asa, 380
Greece, of antiquity, 39–46
Greeks, early development of science, 18–20, 38
Greene, Edward Lee, 124, 142
on Theophrastus, 35, 37
Grew, Nehemiah, 205, 382, 384, 385–388, 436
Guy de Chauliac, 157

H

Hales, Stephen, 397–400, 436
Haller, Albrecht von, 333, 440–444
on Theophrastus, 35
Hammurabi, laws of, 9
Harvey, William, 179, 182–189, 193–195, 334, 439
influence of Galen, 63
magnifying glasses used, 187
Heart
(see also, Circulatory system)
Harvey's study of, 187–189, 193–195
Heider, entomologist, 277
Helmholtz, Hermann von, 455, 460–462
Herbals
(see also, Botany; Natural history)
Herbarum vivæ eicones, 127–131
sixteenth century, 126–152
term defined, 127
Heredity, early studies, 4, 7
Hermandez, 302
Herophilus, 40, 43–45
anatomical studies, 44–45
follower of Hippocrates, 44
Hertwig, Richard, 224, 331
Heymons, entomologist, 277
Hippocrates, 13, 23
Histology, introduced by Leydig, 273

Hœfnagel, George, magnified objects published, 199, 201
Hofmeister, Wilhelm, 413, 423–435, 436
Homer, 13
Hooke, Robert, 382
Micrographia, 205, 382
Hortus sanitatis, 107, 108, 120, 125
Human race
(see, Mankind)
Hunter, John, 335, 337–340
Hunter, William, 338
Hydra, 277–280 (see also, Polyps)

I

Illustrations
(see also, Pictures)
first printed, 104–125
Infections, early investigations, 3
"Infusoria," 220–223
Ingen-Housz, Jan, 400, 436
Inoculations, early investigations, 3
Insects,
Bonnet on, 266
cockchafer,
Straus-Dürckheim on, 269–270 (Fig. 78) 271
Dufour's work, 272
early studies, 274–275
histology, introduced by Leydig, 273
Lyonet's work, 257–261
Malpighi's studies, 236, 256
metamorphosis of, Aristotle on, 28–29
modern studies, 275–276
Newport on, 272
plants fertilized by, 276, 412
Réaumur's studies, 263–265
Swammerdam's work, 244–245, 248, (Fig. 66) 249, 256
Isidore of Seville, 77, 79, 102
Isis, scientific publication, 5

J

Janet, entomologist, 277
Jansen, Zacharias, 198, 199
Jenner, 338
Jennings, 224
Joblot, 219
Jonston, John, 298, 300–301
Jung, 361, 436

K

Kandel, David, 138
Kielmeyer, 343
Kircher, Athamasius, enlargement of organisms, 201
Klein, Jacob Friedrich, 311
Knight, Andrew, 407, 436
Koch, 3
Kœbreuter, Joseph G., 371, 410, 411–412, 415
Kölliker, 394
Konrad von Megenberg
(see, Conrad von Megenberg)
Korschelt, entomologist, 277

L

Lamarck, 24, 324–325, 389
Lankester, E. Ray (Sir), 15
Leeuwenhoek, Antony von, 25, 205, 206–218, 250–253
bacteria discovered by, 214–216, 251
circulatory system studies, 217, 251
compared with Swammerdam and Malpighi, 254–255
general biographical observations, 252–253
microscopes of, 207–211, 250
"Microscopic Observations" and others, 251–252
protozoa discovered by, 211–213, 260
red corpuscles observed by, 252
spermatozoa discovered by, 218, 250
Leonardo da Vinci, 65, 156, 159–161, 165
on circulatory system, 190
Leuckart, Rudolph, 328–329
Lewes, George Henry, on Aristotle, 24, 25, 26
Leydig, Franz, 273, 274, 275
Libby, Walter,
acknowledgment to, iv
on history of science, 226
on Hunter, 340
scientific contributions, 5
Libraries
(see also, Books)
Alexandrian, 40–42
mediæval, 78
Roman, 47
Linnæus, 25, 310–321, 364–368, 410, 436

Linne
(see, Linnæus)
Lister, 3
Literature, of thirteenth century, 90
"Living Pictures of Herbs," by Brunfels, 127–131
Locy, Ellen Eastman, acknowledgment to, iv
Ludwig, Carl, 455, 457–458
Lungs, Malpighi on, 234
Lyceum of Aristotle, 21, 31, 33, 34
Lyonet, Pierre, 257–261

M

MacVeagh, Lincoln, acknowledgment to, iv
Macedonian Empire, influence on Greece, 39
Magendie, François, 449–451, 465
Magic,
Pliny on, 53
science and religion, relation during prehistoric age, 17, 52–54
Thorndike on, 52
Magdalenian period, 11
Magnus, Albertus, 25, 72, 91–97, 436
Malpighi, Marcello, 12, 25, 229–240, 334, 382–384, 385, 387–388, 436
compared with Swammerdam and Leeuwenhoek, 254–255
on circulatory system, 188
on plant nutrition, 397
user of microscope, 205
Mankind,
Aurignacean culture-period, 11
Crô-Magnons, 13–18
Magdalenian period, 11
Neanderthalers, 14
palaeolithic period, 10
prehistoric period, 13
primitive characteristics, 10–12
Manuscripts
(see, Books)
Marcgrave, George, 303–305
Materia medica, of Dioscorides, 54–62
Matthiolus, 136
Mattiolo, Pierandrea, 146, 147
Meckel, J. Fr., 355–356
Medicine,
Arabian activities during Middle Ages, 83–87
early practice of, 9–11
"Ebers Papyrus," 9
Erasistratus, founder of Alexandrian school, 43
Greek studies, 19
Herophilus, founder of Alexandrian school, 43
preventive, early investigations, 3
primitive observations, 10
science of, developed during Alexandrian supremacy, 43–46
Mendel, 4, 415
Meyen, 389
Meyer, on Albertus Magnus, 94–95
Micro-organisms
(see also, Bacteriology)
Animalcula infusoria, first standard treatise, 220
"Chaos" of Linnæus, 213
discovery, 206
Hooke's observations, 205
importance of study, 224
Kircher's observations, 202
Microscopes,
early discoveries, 197–211, (Fig. 56) 212
first general use of, 196
Kircher's use of, 201, 202, (Fig. 49) 202
Leeuwenhoek's, 207–218
Malpighi's pioneer microscopist, 235
Middle Ages, conditions and influences, 72
Milne-Edwards, Henri, 350
Mirbel, 389
Mohammedans, Greek manuscripts preserved by, 83
Moldenhawer, 389
Monasteries, influence during Middle Ages, 77
Mondino, 65, 156
commentaries by Berengario, 162–163
Moritz, Johann (Count), 303
Morphology
(see, Biology)
Morris, William, on "Breidenbach's Travels," 116
Mosquito-problem, effects of, 275
Mouffet, use of magnifying lenses, 199, 201
Mule, Gesner's sketch, 293

Müller, Johannes, 356–357, 376, 451–455, 456
Müller, Otto Fr., 213, 220–221
Müller, W. Max, 9
Muscles,
  Galen's observations, 67
  Haller on, 442
  Swammerdam on, 248
  willow moth, 257–259
Museum at Alexandria, 41
Mustelus lævis, Aristotle on, 28
Myriopoda, Newport on, 272

N

Nägeli, Carl, 393–396, 413, 415, 417, 436
Natural Faculties, by Galen, 20
Natural history
  (see also, Biology; Botany; Herbals; Science; Zoölogy)
  Aldrovandi's work, 298–300
  earliest printed illustrations, 103–125
  Gesner's work, 290–298
  Greek studies, 18–20, 38
  Linnæus' work, 310, 313–314, 317–321
  Magnus' work, 92–96
  Malpighi's work, 229–240
  Marcgrave's work, 303–305
  of Antiquity, 13–38
  Physiologus, 75–77
  Pliny on, 48–54
  primitive observations, 8–12
  Ray's work, 306–310
  Roman Period, 47–71
  sixteenth century, 126–152
  sixteenth to eighteenth century, 283, 301
  Swammerdam's work, 240–250
  thirteenth century, 89–102
Neanderthalers, 14
Neckam, 95, 102
Needham, on spontaneous generation, 218
Neleus, 33
Nerves,
  Bell's observations, 447
  Bernard on, 468–469
  Galen's observations, 66–68
Nestorians, 82
Neuberger, on Galen, 68
Newport, George, 272–273
Newton, Isaac (Sir), 397
Nicholas of Cusa, 97

O

Œsophagus, Galen's observations, 70
On the Properties of Things,
  by Bartholomew, 99–101, 108, 115, 117, 118
Organic evolution
  (see, Evolution, organic)
Osler, William (Sir), 5
Ostriches, Magnus on, 93–94
Oviedo, 303
Owen, Richard, 353–354, (Fig. 107) 355
Oxygen, discovery of, 438

P

Palæolithic era, 10, 13
Paracelsus, 439
Pasteur, 3
Payne, Joseph Frank (Dr.), 106
Peter of Abano, 97
  Conciliator, 163
Pfeffer, 395, 436
Physiologus, 75–77
Physiology
  (see also, Anatomy; Science)
  ancient, 438
  Bernard on, 462–470
  from Harvey to Bernard, 337–470
  Galen's contributions, 63, 65, 68–70
  Haller's work, 441–444
  Harvey's observations, 186–189, 193–195
  Magendie's work, 449–451
  Malpighi's work, 229–240
  "physiological anatomy," 337
Pictures
  (see also, Illustrations)
  earliest form of record, 13, 14
  earliest, of magnified objects, 199
  earliest printed illustrations, 104–125
  in manuscripts, 103–104
Piso, William, 303, 304
Plants
  (see also, Botany)
  air,
    constituent of, 400, 402
    given off by, 402

Anatome plantarum by Malpighi, 238
Arum described by Cordus, 143
classification, 360
classification,
of Theophrastus, 37
descent of, 433
fertilization of, 430–436
by insects, 276, 412
hybridization, 412
microscopic structure, Grew's observations, 205
mullein, described by Boch, 139
nutrition, 397, 400, 409
pictures in manuscripts, 103–104
sexuality of, 409–413
sketches of, 122, 123, 129, 130
Plenciz, belief in germ theory of disease, 202
Pliny, the Elder, 25, 44, 47, 48–54
Pliny, the Younger, 48
Plutarch, classical author, 44
" Polygastrica," 222
Polyps, 432 (see also, Hydra)
Praxagoras, 44
Priestly, 403
Primitive man
(see, Mankind)
Printing, first use of, 104
Protoplasm, 4, 333, 382, 391, 394, 408
Protozoa, 219, 224
Leeuwenhoek, discoverer, 211–213
Ptolemies, 40, 41, 42, 45, 62
Puch der Natur, 102, 105–107, 109–115

R

Rabbit, Gesner's sketch, 292
Rathke, Martin Henry, 356
Ray, John, 25, 144, 305, 306–310, 362–363, 436
Réaumur, René, 220, 262–265, 446
Records
(see also, Books; Illustrations; Pictures)
Greeks, earliest written of, 18
pictures, earliest form, 13, 14
Redi, 218, 250
Reindeer
(see, Deer)
Religion,
crusades, 89–90
early development, 12
education, relation between, during seventh and eighth centuries, 79–80
influence during Middle Ages, 73–75
monasteries, 77
" Revolutions of the Heavenly Bodies," by Copernicus, 154
Rœsel, von Rosenhof, 262, 266, (Fig. 76) 267, 268
Roman Period, natural history during, 47–71
Rondelet, Guillaume, 286, 287, (Fig. 86) 289
Royal Society of London, 226, 227
Ruel, French botanist, 136

S

Sachs, Julius, 37, 364, 366, 370, 371, 374, 380, 394, 395, 397, 400, 407–409, 417, 419, 436
Saint-Hilaire, Geoffroy, 344, 349
Saracens, 42, 81
Sarton, George (Dr.), 5
Schaudinn, Fritz, 224
Schleiden, Matthais J., 376, 413, 416, 417–423, 436
textbook of, 419–422
Schools,
Bagdad university, 82
Brunfels, at Strassburg, 128
founded in Spain, 83
Lyceum of Aristotle, 21, 31, 33, 34
medical, in Alexandria, 43–46, 47
scientific, established during seventeenth century, 226
thirteenth century, 91
Schott's, *Magia optica,* 203
Schultze, Max, 395
Schwann, 394
Science
(see also, Botany; Natural history; Physiology; Zoölogy)
associations formed during seventeenth century, 226
early development, 10–12
from Galen to thirteenth century, 72–88
Greek development of, 18–20, 38, 39–46
herbals of sixteenth century, 126–152

magic, relation between, 17, 52–54
of antiquity, 13–38
of thirteenth century, 89–102
recent interest in, 4–5
Roman Period, 47–71
sixteenth century advancement, 153
Sedgwick, 5
Senebier, Jean, 403, 404
Seneca, on magnifying properties, 197
Sepia, Aristotle's observations, 20, 27, 28
Serum, early investigations, 3
Servetus, 190, 192
Severinus, 335
Silkworm, Malpighi on, 235–237
Singer, Charles, 5, 74
acknowledgement, 18
on Dioscorides, 59
on herbals, 126
on invention of microscopes, 199
Skin, Malpighi on, 234
Snail, Swammerdam on, 247
Spallanzani, Lazzaro, 220, 438, 444–447
on spontaneous generation, 218
Specklin, Vitus Rudolphus, 134
Spectacles, early use of, 198
Spermatozoa, Leeuwenhoek's discovery, 218
Spinal cord, Galen's observations, 66–68, 70
Sprengel, Konrad, 410, 412–413, 415
Star-fish, 281
Steno, 242
Stensen
(see, Steno)
Strasburger, 395, 436
Straus-Dürckheim, 268–270
"Structure of the Human Body," by Vesalius, 168
"Su," Frankfort edition of Gesner, 296–297
Sudhoff, Karl, 5, 74
anatomical sketches reproduced by, 159
Swammerdam, Jan, 25, 240, (Fig. 64) 241, 242–250
compared with Malpighi and Leeuwenhoek, 254–255
water-fleas discovered by, 212
Sylvius, Franciscus, 164
Sylvius, Jacobus, 156, 164
Systema naturæ, 316–318

T

Tertullian, 74
Tessier, 344
Theophrastus, 34, 35–38
associated with Lyceum of Aristotle, 21, 34
botanical observations, 18, 20–21, 31–32, 34
"father of botany," 9, 38, 435
friend of Aristotle, 20
Thermometer, Réaumur, inventor, 263
Thomas of Cantimpré, 25, 94, 99, 101, 106, 109
Thompson, D'Arcy Wentworth, translator of Aristotle, 27, 33
Thorndike, Lynn, 74
acknowledgement to, iv
"*History of Magic,*" 52
on early relation of magic and science, 17
on Pliny, 48
scientific contributions, 5
Toxins, early investigations, 3
Tragus
(see, Bock, Hieronymus)
Trembley, Abraham, 277–281
Treviranus, 389
Trevisa, John, translator of Bartholomew, 100
Turner, William, 136, 285
Tyler, scientific contributions, 5

U

Universities
(see, Schools)
Ureters, Galen's observations, 68

V

Vaccinations, early investigations, 3
van Helmot, 397
van Leeuwenhoek, Antony
(see, Leeuwenhoek, Antony van)
Varro, 47
Verworn, 452, 462
Vesalius, Andreas, 65, 71, 166–175
anatomical studies mark new era, 153, 165–166, 178
De humani corporis fabrica, 168

Fabrica, 168–171, 172–173
influence of Galen, 63
on circulatory systems, 191, 192
Vicq-d'Azyr, Felix, 335, 340–342
Vincent of Beauvais, 97–99, 102
Vines, Professor, on botanical development, 361
Virgil, 47
Vivisection, early use of, 43
von Baer, 326, 375
von Haller, Albrecht
(see, Haller, Albrecht von)
von Mohl, Hugo, 376, 389–392, 394, 413, 417
von Rosenhof, Rœsel, 220
von Sachs, Julius
(see, Sachs, Julius)
von Siebold, Karl Theodor, 327–328
von Stein, 223

W

Wallace, Russell, 24
Weber brothers, 455
Weismann, entomologist, 277
Wheeler, entomologist, 277
Willow moth, 257–263
Willughby, Francis, 305, 307
Winans, Walter, 15
Wöhler, 456
Wolff, Caspar F., 389
Wotton, Edward, 284–285

Z

Zoölogy
(see also, Animals; Natural history; Science)
botany, similarity of development, 7
primitive observations, 10–12